Magnetic Field Management

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Cover: The ability to map magnetic field strengths inside residences can help researchers determine the relative importance of field sources, such as power lines, grounding systems, and electric appliances.

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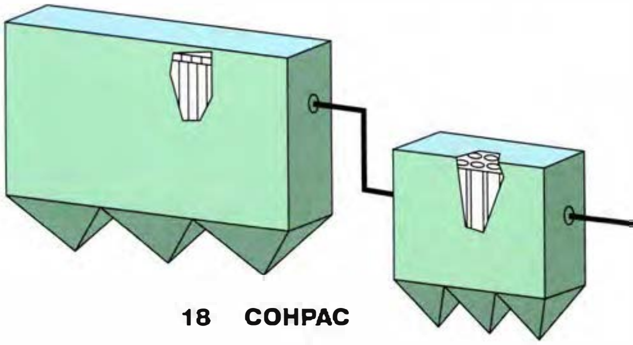

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PRODUCTS

EPRI-sponsored deliverables now available to utilities and their customers

EMDEX Lite

EMDEX Lite is the newest member of a family of hand-held instruments for measuring personal exposure to magnetic fields and surveying field levels in homes, offices, and factories. A smaller version of the popular EMDEX II, this new model weighs only 6 ounces and is 5 inches long. It easily fits into a shirt pocket. Utilities are already finding EMDEX Lite invaluable in responding to customer requests for field measurements and in surveying utility facilities. The instrument's battery life is estimated to be in excess of 200 days.

For more information, contact Stan Sussman, (415) 855-2581. To order, call Enertech Consultants, (408) 866-7266.

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Be it a software code, a piece of hardware, a series of guidebooks, or any other type of EPRI product pertaining to generation, storage, and environmental control issues, you'll find a description of it on GENCAT. This user-friendly electronic product catalog, a software version of the generation, storage, and environmental control components of EPRI's popular Product Book series, is intended to help EPRI members find what they need — fast. GENCAT offers rapid search and retrieval capabilities for product descriptions, report abstracts, technical bulletins, utility case studies, and more. Graphic displays help illustrate everything from emission control technologies to boiler tube repair techniques. GENCAT includes a benefits

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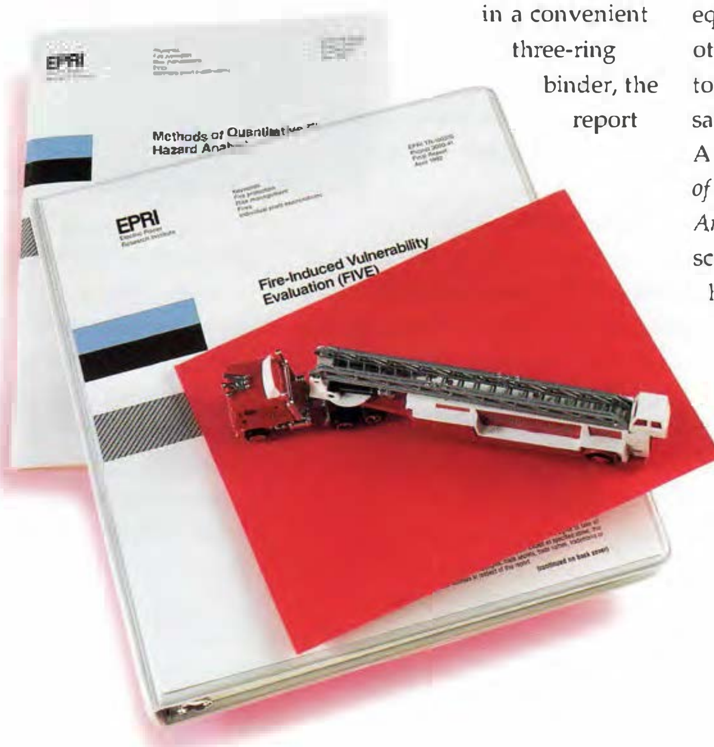
Designed to please even the most demanding of today's energy-conscious residential customers, the Powermiser™ heat pump system combines space heating, air conditioning, and water heating in a single, highly efficient electric appliance. Powermiser markedly exceeds the 1992 Department of Energy standards and is 30% more efficient than conventional combined electric heat pump and waterheating systems. In addition to other energy-saving aspects, Powermiser uses heat rejected from the cooling process to help with water heating. And it features operating modes with dehumidification to provide greater comfort. Powermiser is the first line of integrated heat pumps to offer a model that is specifically designed for mobile homes.

For more information, contact Terry Statt, (415) 855-2011. To order, call Jim Kelly at Nordyne, Inc., (314) 878-6200.

calculation module that allows users to estimate site- and application-specific benefits of EPRI products. *For more information, contact Greg Lamb, (415) 855-2449, or Liane Freeman, (415) 855-2755. To order, call the Electric Power Software Center, (214) 655-8883.*

FIVE Methodology for Fire Prevention

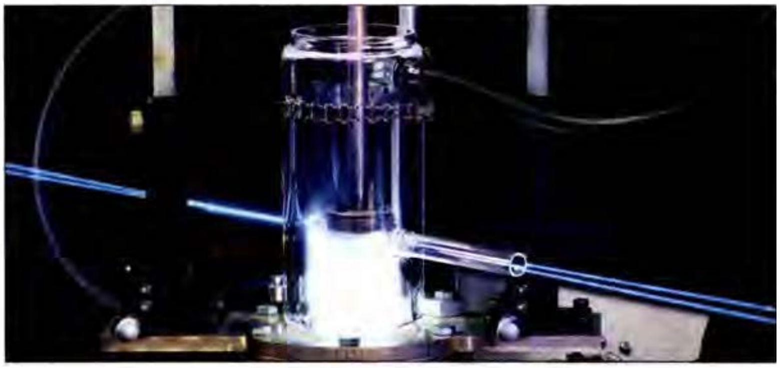
A Nuclear Regulatory Commission–approved procedure, the Fire-Induced Vulnerability Evaluation (FIVE) methodology (described in EPRI report TR-100370) is a cost-effective, step-by-step technique for assessing a nuclear power plant's susceptibility to fire. Packaged in a convenient three-ring binder, the report presents a screening process that uses plant-specific data for evaluating the sequence of events during a fire. The objective is to determine the availability of the plant equipment, cabling, and other components necessary to achieve and maintain a safe shutdown of the reactor. A companion report, *Methods of Quantitative Fire Hazard Analysis* (TR-100443), describes the models for fire hazard analysis used in the FIVE methodology.
For more information, contact Richard Oehlberg, (415) 855-2082. To order, call the EPRI Distribution Center, (510) 934-4212.



NCW Manager

Managing noncombustion wastes, such as used batteries, utility poles, solvents, and asbestos, can be an overwhelming task for utilities. NCW Manager significantly simplifies this task by helping users identify and evaluate waste management options. This software code guides users through the identification of all kinds of feasible alternatives, including the reduction of waste at its source, recycling, and treatment and disposal. The program can take into account utility-specific information, such as local disposal requirements and the availability of existing facilities. It automatically ranks waste management options in terms of environmental and health risks, direct and indirect costs, potential liabilities, and other criteria. Soon to be released is a new, user-friendly version with enhanced graphic capabilities.
For more information, contact Bob Goldstein, (415) 855-2593. To order, call the Electric Power Software Center, (214) 655-8883.

Diamond Coatings for Wear Resistance



The recent development of relatively inexpensive methods for coating metals and semiconductors with a thin layer of synthetic diamond promises a variety of intriguing applications in the utility industry. Initially, EPRI researchers focused on the possibility of using these coatings to create a new type of carbon-based semiconductor that could withstand high temperatures and radiation levels and thus be used to monitor plant operations in locations that are now inaccessible. So far, however, it has not been possible to grow single-crystal diamond films that are thick enough for useful semiconductor devices. As a result, researchers are now focusing on an application that appears to have a nearer-term payoff: diamond coatings that can be used to harden critical power plant components, making them more resistant to wear, corrosion, heat, and radiation.

Some diamond-coated products are already commercially available. These items, generally small, include tools, lenses, and heat sinks for integrated circuits. For utility applications, EPRI is seeking ways to use diamond coatings on much larger equipment and under more extreme conditions. On valve seats, for example, a diamond coating would improve wear resistance and heat dissipation and—in nuclear plants—reduce the amount of radioactive wear products circulating in primary coolant loops.

Critical problems must be solved, however, before such utility applications become widespread. For example, diamond films do not adhere well to ferrous metals, which are the most common metals in power plant components. EPRI is sponsoring research that addresses this and other practical issues, while expanding the industry's basic knowledge about diamond-film technology.

Diamond films are deposited on a substrate by chemical vapor deposition, in which intense heat is used to dissociate hydrogen and methane molecules into their atomic constituents. As the carbon atoms from the methane begin to coalesce on the substrate surface, hydrogen atoms react preferentially with the carbon in the form of graphite, leading to the growth of an almost-pure diamond layer.

To improve the adherence to iron and other ferrous metals, researchers at the University of Nebraska are examining variations of the basic deposition method, including the addition of a "priming" layer of material on the substrate. Related studies at Stanford University's Department of Materials Science and Engineering have produced a new way to measure how well a diamond film is adhering to a substrate. And researchers at Stanford's School of Engineering are seeking ways to lower the cost of applying diamond coatings, including the use of a plasma torch.

EPRI is a member of the Diamond and Related Materials Consortium, which has its headquarters at Pennsylvania State University. This nine-member organization funds generic research related to diamond-film technology. The consortium is also exploring the use of diamond substitutes, such as cubic boron nitride, which is extremely hard and adheres well to ferrous metals.

■ *For more information on the research at Stanford and Nebraska, contact John Stringer, (415) 855-2472; for more information on the consortium, contact Raj Pathania, (415) 855-2998.*

Using Electricity to Breed Bugs

By using electricity to stimulate the growth of certain bacteria, EPRI-sponsored researchers may have identified a cheaper way to produce medicines, polymers, and other high-value products—while opening the door to a new electrotechnology.

Researchers at Clemson University set out to determine whether autotrophic bacteria—microbes that feed on inorganic substances, such as metals—are good candidates for producing genetically engineered substances. What they found was that *Thiobacillus ferrooxidans*, an autotrophic organism that derives its nourishment from carbon dioxide and ferrous iron, could prove a cheaper alternative to *Escherichia coli* and other heterotrophic bacteria currently used for producing medicines and other biotech products.

By altering the genetic code of an organism, geneticists can force the organism to generate a substance it might not otherwise produce. Because heterotrophic bacteria like *E. coli* get their carbon and energy from more-expensive carbon sources, such as glucose, autotrophic bacteria may prove more cost-effective for producing genetically engineered goods.

The key to the Clemson researchers' process was using electrolysis to artificially stimulate the growth of *T. ferrooxidans*. By sending an electric current through an iron-rich solution in which the bacteria were growing, the researchers oxidized the iron, replenishing the bacteria's energy source. At the same time, they provided a carbon source for the bacteria by pumping carbon dioxide–enriched air into their environment. "In a sense, you're giving the bacteria back what they just chewed up," says Stan Yunker, EPRI project manager. "As a result, they never see a depletion of their energy source, and they tend to proliferate more quickly and to much higher densities."

A burgeoning biotech industry based on *T. ferrooxidans* would generate a greater demand for electricity and provide a way for utilities to recycle the carbon dioxide generated by power plants, effectively reducing their contribution to global warming. Economics would require that the bacterial "factories" using this recycled carbon dioxide be located close to the power plants where the gas is produced. Early research indicates that *T. ferrooxidans* is susceptible to genetic manipulation, but questions remain about the kinds of products the bacteria would produce.

■ *For more information, contact Stan Yunker, (415) 855-2815.*

Vortex Patterns Provide Clues to Tube Vibration

Vibrations induced by fluid flow around heat exchanger tubes can cause metal wear and fatigue and force plant shutdowns. Predicting the occurrence of such vibrations on the basis of flow velocity and the diameter and spacing of tubes has been hampered by a lack of basic understanding of the fluid-elastic excitation mechanism, which causes the tubes to vibrate and extract increasing amounts of energy from the liquid flowing around them. An EPRI-sponsored investigation of flow phenomena that helps explain such tube vibration has just been completed at Oklahoma State University.

The experiments used dye injection to show how flow instabilities arise around single cylinders, pairs, and rows. For a single tube, the movement of dye clearly showed the classic case of vortices alternately shedding from each side, resulting in a shifting pressure differential perpendicular to the direction of flow. As flow velocity increased, so did the shedding frequency and the alternating force that made the cylinder vibrate. Vortices created within arrays of tubes were much more complex and led to multistable flow patterns that alternated at irregular intervals.

"This work has given us fresh insight into a very complicated phenomenon," says project manager David Steininger. "Already we're using the results to help calibrate a computational fluid dynamics computer code, called GUST. Eventually this model will help designers build heat exchangers that aren't as subject to destructive vibrations, but right now there's still a lot we don't understand."

Only recently, with the increased power and availability of supercomputers, has it become possible to use a computer model to simulate fluid flow phenomena rather than building a physical test model. If such a computerized simulation is successfully developed, the cost of testing heat exchanger designs for flow-induced vibrations could be reduced from several million to a few tens of thousands of dollars.

■ *For more information, contact David Steininger, (415) 855-2019.*

Managing Mag

THE STORY IN BRIEF Although many questions remain about possible health effects from exposure to electric and magnetic fields (EMF), EPRI is intensifying its efforts to develop methods for field management. These efforts include two major thrusts—exposure assessment, to determine the main sources and intensities of EMF that people are likely to encounter, and the development of mitigation options, to provide member utilities with information and technologies that they can use to reduce field levels in a variety of circumstances. The assessment work has produced state-of-the-art instrumentation for measuring magnetic field levels and a definitive survey of fields in typical U.S. homes. Among the mitigation options currently being explored are low-field transmission line configurations, new residential grounding methods, and innovative concepts for shielding personnel from fields in the workplace.

netic Fields

by John Douglas

EPRI has conducted electric and magnetic field (EMF) research since shortly after its founding, 20 years ago. The primary focus of this research has been on potential health effects, and for the past several years EPRI's program in this area has been the largest in the world. As a result of this work, the electric field component of EMF has been virtually eliminated as a probable cause of health effects, rigorous standards have been established for ongoing epidemiologic studies addressing magnetic fields, and pioneering laboratory studies have been launched to seek biological mechanisms that could explain if and how EMF affects organisms.

Meanwhile, funding is being increased for research on assessing and reducing EMF exposure. Many of EPRI's member utilities are moving forward with field management programs, and the Institute's research in this area is aimed at providing information and tools that can support these programs. EPRI has not, however, taken a position about whether any particular actions are needed, since no cause-and-effect relationship has yet been established between EMF exposure and any health effects, and no hazardous level of exposure has been determined.

"Nevertheless, public pressure to limit such exposure is mounting," says Karl Stahlkopf, director of the Electrical Systems Division. "There is a growing consensus among our members that mitigation options need to be developed within a context of knowledge about EMF sources and exposure levels. The issue isn't going to go away. We intend to be proactive in providing knowledge and assistance to our members and society."

Exposure assessment

Considerable knowledge about EMF sources and exposure levels is already available, thanks to previous EPRI work on instrument development and a definitive survey of fields in typical U.S. homes. Some of the field-measuring instruments developed by EPRI are now commercially available to the industry, and the survey of residential fields is helping focus attention on the most important sources of EMF that people encounter at home.

Obtaining accurate exposure estimates has been one of the most difficult aspects of epidemiologic studies related to EMF. Early studies did not use direct field measurements to determine exposure but instead relied on surrogates—for example, so-called wire codes, which are based on qualitative observations of power lines near homes. To help researchers and utilities overcome exposure assessment problems, EPRI has developed and commercialized three series of instruments for making field measurements under a variety of circumstances.

A stand-alone recorder called STAR makes field surveys by sampling and recording magnetic fields along three axes. The EMDEX family of very small instruments are designed to be worn to measure personal exposure to EMF during daily activities. And the MultiWave system makes simultaneous measurements of fields at multiple points at a site and analyzes the harmonic content of the fields.

To establish a benchmark of field sources and strengths in typical American homes, a nationwide survey was conducted in approximately 1000 randomly selected residences in the service areas of 25 EPRI member utilities. The survey found that power lines were the most significant source of background fields when a home was considered as a whole. In smaller areas, such as parts of a room, ground currents were often the predominant source. The highest peak fields were produced by appliances.

The survey provides a unique source of statistically valid data about residential fields—data that can be used to plan field management strategies and to prioritize future research. EPRI is also using the survey data to assess the validity of the wire codes used to estimate EMF exposure in some epidemiologic studies. (For more information on the survey, see the *Journal's* April/May 1993 issue, p. 18.)

Mitigation options for transmission lines

Transmission lines have been an early focus of EPRI research on mitigation options. Concerns about exposure to EMF created by transmission lines have long been expressed during siting hearings for new lines, and these hearings helped stimulate some of the initial research on the possible health effects of such exposure.

As a source of EMF, transmission lines have several distinguishing characteristics. Because of their height and conductor spacing, the lines produce magnetic fields with much smaller spatial variation at ground level than fields from most other sources. Variations in time are also smaller. The waveshape of transmission line fields is very close to sinusoidal, meaning that there are few harmonics—higher-frequency waves, whose possible effects on organisms are being explored. In addition, fields from transmission lines are oriented mainly in the plane perpendicular to the line; the possible importance of field orientation in interactions with organisms is also being researched.

Theoretically, a variety of techniques could be used to reduce the strength of the transmission line fields experienced in nearby houses. Most of these methods would be applied only in areas where people might receive long-term exposure.

Compaction of lines—bringing the conductors closer together—allows the fields produced by different conductors to more nearly cancel each other. Phase splitting carries this idea one step further by assigning multiple conductors to each phase, thus providing more opportunities for field cancellation. In some cases, transposing the phases on existing multicircuit lines may also enhance field cancellation.

Another basic approach is to create shielding by stringing sections of wire loops parallel to transmission lines. Depending on the amount of shielding desired, these loops can act passively, through currents induced by EMF from the transmission lines, or they can have currents actively imposed, creating fields that cancel those from the transmission lines. To eliminate 60-Hz fields from a transmission line altogether, the line can be converted to a high-voltage direct-current system. However, that is a relatively expensive option for lines shorter than about 300 miles.

Three low-field transmission test lines have been built at EPRI's High-Voltage Transmission Research Center (HVTRC) in Lenox, Massachusetts. A cruciform split-phase line uses two conductors for each phase, arranged compactly in the form of an X. Energized at 115 kV and 1000 A, the test line is expected to produce a ground-level magnetic field of 1.5 milligauss (mG) at waist level 50 feet from the center of the line, compared with 40 mG for a conventional line. A compact twisted line, which features midspan transposition of conductors, has a calculated field of 4.1 mG at 50 feet. A vertical split-phase line, with multiple conductors for each phase arranged roughly in an I formation, is expected to produce a field of 2.1 mG at 50 feet. Experiments are under way to verify these calculated field values and to test the three line configurations for practicality, corona production, and insulation problems. Other test lines may be constructed in the future.

In some cases, it may be possible to upgrade the capacity of a transmission line while reducing the magnetic fields it produces. One option for achieving both of these goals is to convert the line from a three-phase, double-circuit configuration to a six-phase, single-circuit configuration. In the first utility demonstration of this concept, conducted by New York State Electric & Gas Corporation with EPRI participation, a 1.5-mile segment of double-circuit 115-kV line was converted to six phases and was put into service in 1992. The conversion resulted in a 40% increase in capacity with 60% lower magnetic fields.

Distribution system options

A major source of magnetic fields from overhead distribution lines is unbalanced currents on the three phases of the line. Ideally, the sum of currents flowing along conductors toward a load is zero—that is, there is no *net* current along the line. Under such circumstances, the magnetic fields produced by one conductor are largely canceled by those produced by the other conductors. However, when a substantial current returns to a distribution transformer through the ground rather than through the neutral conductor of the line, a net current exists. The magnetic field produced by this net current is not canceled and may become a significant source of EMF in nearby homes.

The search for field mitigation options for overhead distribution lines is focusing on ways to balance the currents associated with the various phases and thus reduce the net current. The initial stages of this work include the collection of statistical data on the operating characteristics of distribution lines and the customization of computer models to incorporate these data. Various methods are being considered to reduce the return of current over paths other than the neutral conductor. Also, in some cases, line compaction and other changes in conductor configuration may be effective. And EPRI is working with one member utility to determine if shield wires running parallel to a distribution line can be effective in reducing fields that are causing computer interference in a nearby office building.

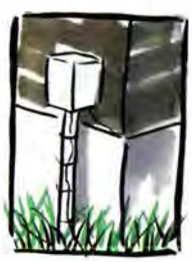
Underground distribution lines generally produce low magnetic fields in homes, but they can have magnetic field

Exposure Assessments Highlight Need for Different Management Strategies

The development of effective means of reducing magnetic fields or managing human exposures to fields may be guided by new information from a nationwide EPRI survey of 1000 homes. This survey confirmed widespread exposure to typically low magnetic field levels from a large number of sources. In general, power lines were found to be the dominant source of indoor magnetic fields for a home considered as a whole, although ground currents may be the main contributor to fields in individual rooms. Because power lines are usually situated some distance from homes, fields from these sources are typically only a few milligauss inside residences.

Transmission lines Although homes near transmission lines have some of the highest median indoor fields, in most cases these lines account for only a fraction of the field levels to which people are exposed indoors. Transmission lines generally produce higher field levels in homes than do distribution lines. A variety of alternative transmission line configurations that offer reduced magnetic field levels at the right-of-way are being evaluated.

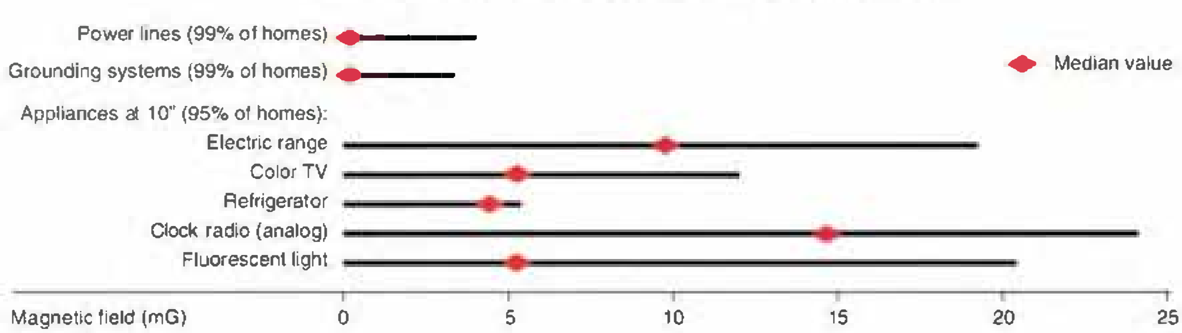
Distribution lines Whereas magnetic fields from transmission lines can be reduced by changes in configuration, this method has relatively little effect on magnetic fields from distribution lines. Because of varying customer loads, harmonics from household appliances, and the fact that part of the current flows into the earth at grounding points, different methods must be used to lower fields from these lines. Better ways to balance the electrical load and reduce the flow of current in pipes and through the earth may be required.



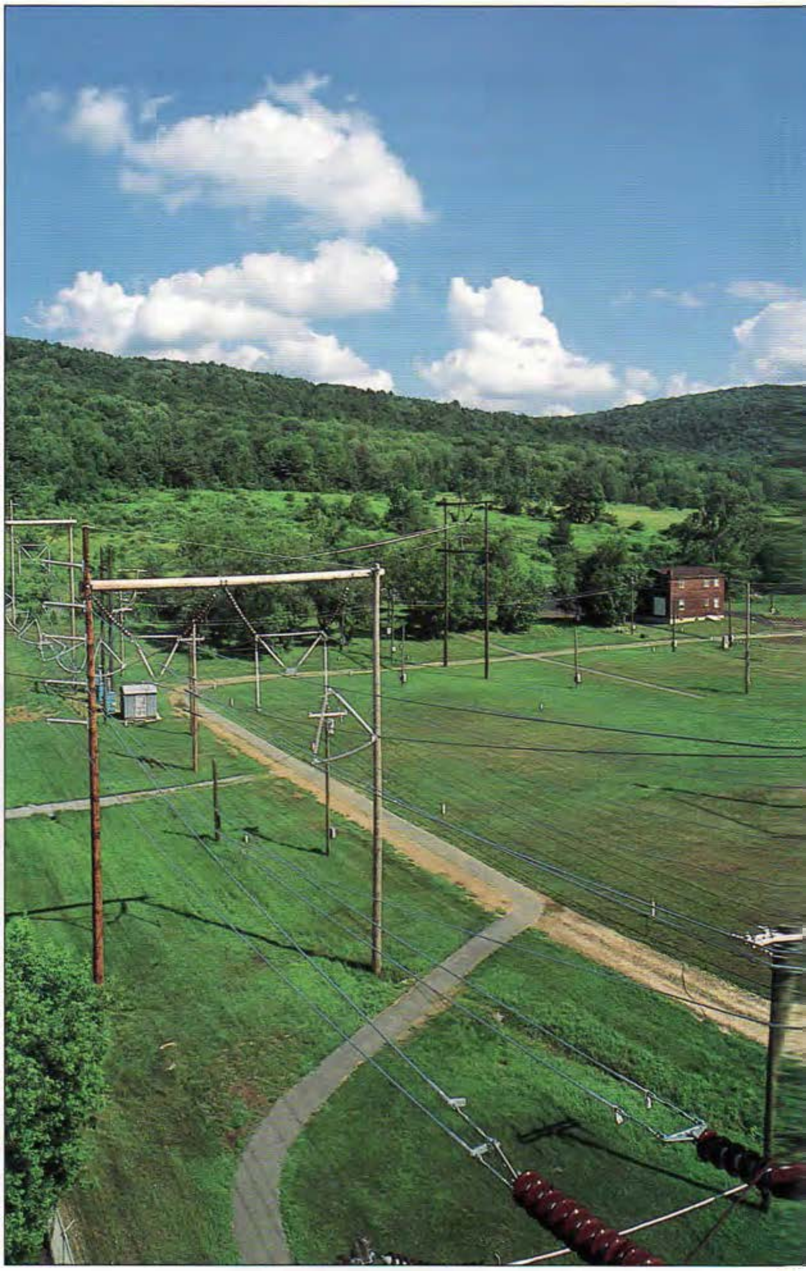
Grounding connections Neutral-to-ground connections at a customer's house are important because they protect against shock and fire from fault currents. However, multiple grounding connections at customer sites, together with current-carrying metal water pipes, provide numerous paths whereby neutral return current can flow back to the utility distribution system instead of using the secondary neutral wires. Such return currents are not self-canceled and can be sources of significant magnetic fields. Interconnected water pipes can provide paths for substantial neutral current to flow between neighboring residences. Since changes in grounding practice could pose a safety hazard, any such changes must involve a broad community of utilities, safety code groups, trade unions, and regulators.

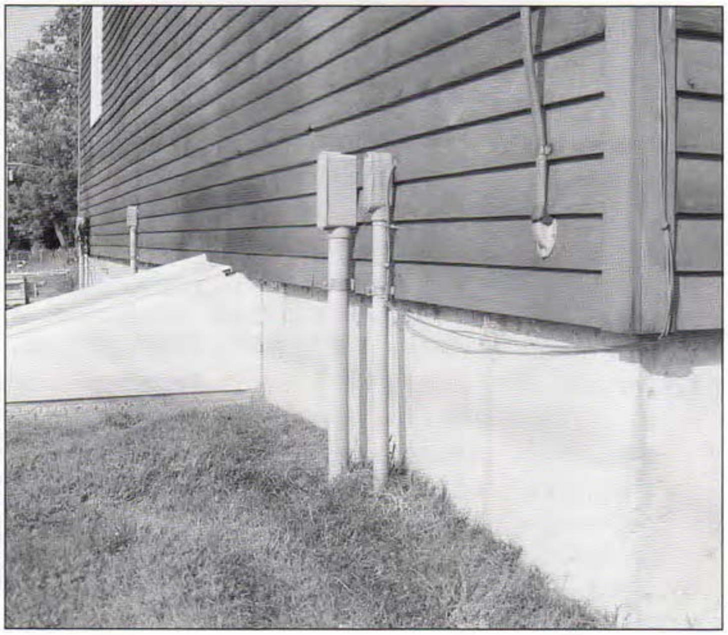
Appliances Probably because kitchens are the location of many electric appliances, they typically have slightly higher median magnetic field levels than other rooms in a residence unless significant ground currents are a factor. Although electric appliances can produce the highest peak fields typically found in residences, the fields decline much more rapidly with distance from the source than do fields from power lines and ground currents. Many appliances, particularly those controlled by solid-state devices, can create higher-frequency fields in addition to 60-Hz magnetic fields. Manufacturers have redesigned some appliances, including some models of electric blankets and computer monitors, to reduce magnetic fields.

TYPICAL SOURCES OF RESIDENTIAL EMF EXPOSURE



A Real-World Model for Residential Fields A focal point for much of EPRI's work on residential magnetic fields is the Magnetic Field Research Facility, located at the Institute's High-Voltage Transmission Research Center in Lenox, Massachusetts. The facility's specially designed and instrumented house offers researchers a unique environment for creating and analyzing magnetic fields from various sources under controlled conditions in a simulated residential neighborhood. The setup includes overhead and underground distribution lines, simulated electrical loads, and water systems with variable-resistance grounding connections. Special field measurement and recording instruments and analytical software have been developed as part of the research. Early work at the facility highlighted the role—since confirmed in a nationwide survey—that ground currents can play in the complex dynamics of indoor magnetic fields. The facility also conducts periodic training and educational courses on magnetic field measurement for utility and other personnel. A two-day workshop is planned for this September.





levels comparable to those of overhead lines when there is an appreciable net current. Since the cable is often near the surface and sometimes close to buildings, these fields may not have the opportunity to decrease with distance as fields from overhead lines often do. Field management research for cables is beginning with efforts to determine more completely the operating characteristics of underground lines, develop suitable computer models, and find ways of balancing the currents flowing through the various conductors.

A much more complicated task than studying individual lines—the focus of the work discussed above—is modeling fields in and around transmission or distribution substations. Although the current flowing on the substation bus is the major source of magnetic fields, substations contain numerous other sources—including transformers, reactors, and metal-clad switchgear—arranged in complex configurations. EPRI's initial approach to this difficult modeling task has been to build a reduced-scale substation model and use probes to characterize the magnetic fields. A digital computer model has also been developed and is being verified for accuracy by measuring fields in actual substations. Eventually the computer model will be used to examine various field mitigation methods, including the possibility of shielding substation workers and using remote-control devices so that workers can avoid the locations with the highest fields.

Grounding—a special challenge

Finding ways to reduce the fields from ground currents in homes presents a special challenge to electric utilities, since the mitigation efforts will usually involve changes on the customer's side of the meter and will possibly require modification of the National Electrical Code (NEC). In addition, where grounding to water pipes is concerned, other utilities may need to be consulted.

Grounding the neutral wire of an electrical distribution system protects customers against shock and fire by facilitating the fast operation of a fuse or a circuit breaker in the event of a fault. The NEC currently calls for grounding to a water pipe at the service entrance of a residence. This means that the return current can flow back to the distribution transformer through a parallel ground path instead of through the neutral conductor. When such currents are conducted by pipes inside a home, they can be a substantial source of residential magnetic fields.

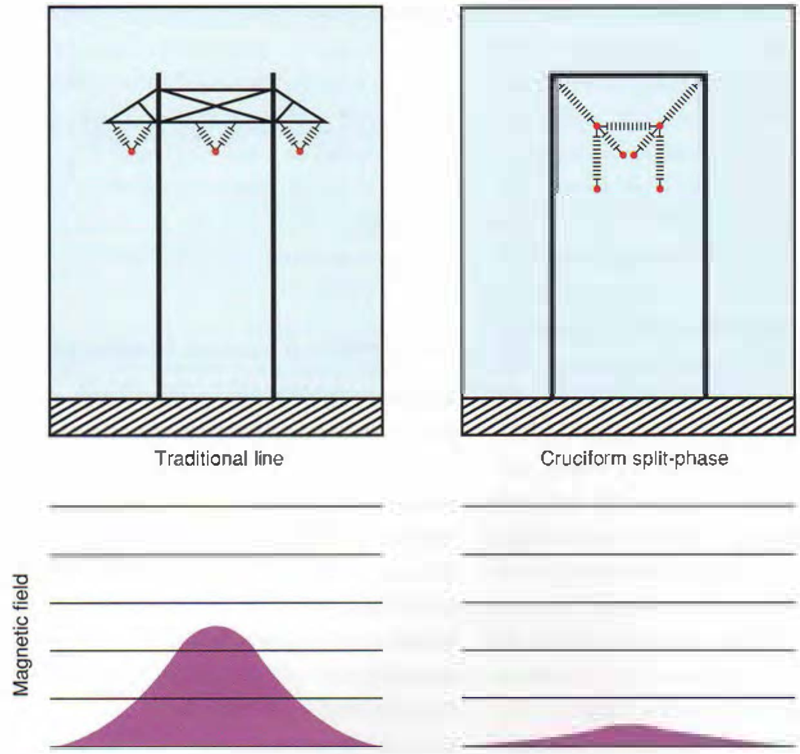
Some currents in pipes originate on the customer's premises. Usually these currents result from the regrounding of the neutral wire at locations inside a residence, in addition to the prescribed grounding at the building's service entrance. Such regrounding may or may not violate the NEC, depending on the circumstances. Ground currents in a customer's water pipes may also originate on the premises of a neighbor. Sometimes this occurs when there is damage to the neutral connection at the neighbor's service entrance. In such cases, return currents may flow from the neighbor's house through a water main and then through pipes in the nearby customer's house on their way back to the distribution transformer.

It may be possible in some circumstances to reduce the pipe current and still follow the NEC guidelines. Customers, working with a licensed electrician, may be able to eliminate improper regrounding inside a residence. Also, in some cases, a licensed plumber may be able to insert insulated joints in residential water lines. Such joints would electrically isolate each home and prevent the intrusion of currents from neighboring premises.

Changes in the grounding practice prescribed by the NEC are also being suggested. One suggestion is based on the system common in some European countries: ground the neutral conductor only at the distribution transformer, and run a separate ground wire (in addition to the neutral) to each residence. This would mean that the service connection to most homes would involve four wires rather than the three commonly used today. Such an arrangement would eliminate the connection to the water pipe at the home and thus reduce pipe currents. Appliances could also be grounded directly to the fourth wire, rather than to a water pipe. Such a scheme would probably require the

Evaluating Field Management Options

Among the magnetic field management options now being considered by some utilities in response to public concern are low-field configurations for transmission lines. One low-field configuration, shown in the drawing, employs a cruciform split-phase design that may offer a substantial magnetic field reduction, compared with a conventional line configuration.



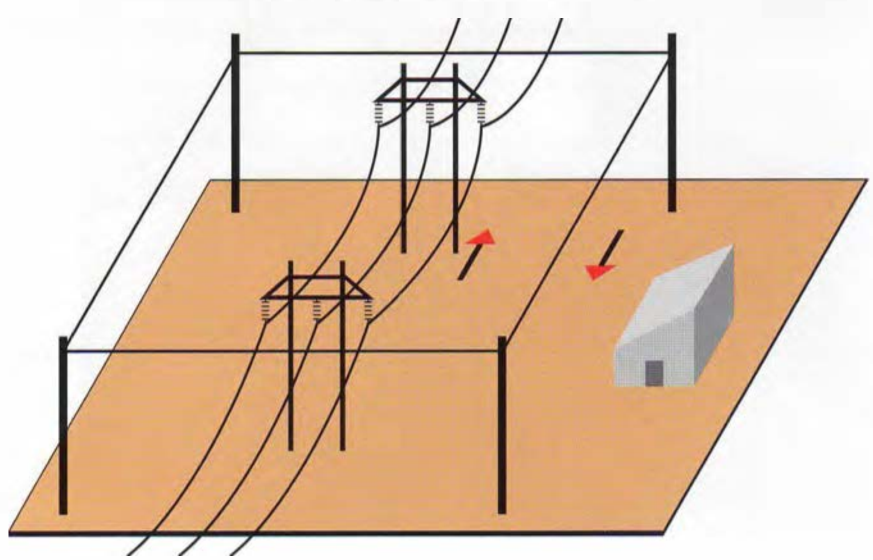
EPRI's High-Voltage Transmission Research Center has constructed three low-field lines for testing: the cruciform design, another split-phase design, and a compact twisted-conductor configuration. Other options may enable utilities to upgrade a line's capacity while substantially reducing its magnetic field; conversion from three-phase to six-phase transmission is one possibility being explored.

Low-field test lines at HVTRC (left to right: vertical split-phase, twisted-conductor, cruciform split-phase

Six-phase transmission test line

Also under evaluation are shielding-wire concepts in which additional conductors are used to cancel fields around power lines near buildings or populated areas. EPRI is investigating other shielding approaches for utility personnel who work near high-field equipment.

Shielding-wire concept



use of additional protection equipment, which would respond to a fault current flowing over the ground wire.

Pilot research on how ground currents originate and which paths they flow on has already been conducted by EPRI and Empire State Electric Energy Research Corporation. The most-promising grounding options are now being prepared for more testing and evaluation. Further research will also be conducted to determine the impact of possible grounding changes on distribution system operations and protection practices. Preliminary meetings have been held with NEC committee members and others involved in grounding practices, including representatives of the American Water Works Association. The association particularly supports the suggestion to electrically isolate water mains from residential grounding in order to prevent injury to water utility personnel.

Personnel shielding

Shielding people from magnetic fields is difficult. For electric fields, adequate shielding may be provided by walls, thin metal sheets, or even wire mesh. Reducing magnetic fields, however, requires thick plates of specially alloyed metal. With existing materials and design methods, such shielding is usually prohibitively expensive. EPRI is attempting to overcome these obstacles through a $2 million project just getting under way to explore new shielding materials and design concepts.

The first priority of the project will be to develop a handbook that utilities can use to determine which types of shielding may meet their needs. This state-of-the-art handbook, to be published near the end of 1993, will summarize the known information about 60-Hz shielding and present that information in a form readily usable by utility engineers. Accompanying the handbook will be software that models a magnetic field source and the proposed shielding material or field-canceling wire loop, then calculates the field reduction that can be achieved.

The next priority of the project will be to conduct full-scale tests on various shielding designs, using existing materials. Shielding effectiveness will be determined both for steady 60-Hz fields and for harmonics. The results will be published as a shielding design manual, with accompanying software.

Finally, project researchers will explore new shielding materials, including special polymers that may exhibit 60-Hz shielding properties. In addition, they will look for ways to shield sensitive computing equipment from 60-Hz fields near transformer vaults and cable runs in commercial and industrial settings.

"In most cases, field reduction is best accomplished by lowering the field at the source, but that approach works best for new facilities or new power lines," says John Dunlap, project manager in the Electrical Systems Division. "For existing facilities, or for protecting workers temporarily in high-field areas, shielding may be the only viable option. A major breakthrough on a lower-cost shielding material is a worthwhile goal for research, but no real promise of this is now on the horizon."

Service to members

Already, some field management tools are available for use by EPRI's member utilities. The EMWorkstation, for example, is an integrated set of software modules that engineers can use to model EMF produced by power lines and to estimate personal EMF exposure in specific circumstances. The workstation format provides a common user interface and enables the individual software modules to share data. Five EMWorkstation modules are currently available, and others will be added as the results from ongoing research become available.

The EXPOCALC module calculates fields in the vicinity of overhead transmission lines and models human exposure to those fields, given information about the amount of time spent near the lines. ENVIRO produces lateral profiles of EMF near overhead transmission lines in two dimensions, assuming that all conductors are infinitely long. In the near future, MAG3D will be able to produce more-detailed EMF profiles in three dimensions and to take into account the sag of lines and their deviations from parallel paths. BLANKET models the magnetic fields produced by electric blankets. Other EMWorkstation modules communicate and analyze data collected by EMF survey instruments.

One key to the success of EPRI's field management initiative is the availability of unique research facilities where full-scale experiments can be conducted to develop exposure assessment tools and test field mitigation techniques. HVTRC has been a major contributor to EMF research for several years and recently added the Magnetic Field Research Facility to enhance those efforts. The new facility models a typical residential neighborhood, including a 23-kV primary feeder, secondaries, and service drops for 18 houses. Its primary purpose is to provide engineers with a laboratory for making field measurements, verifying software, and experimenting with field reduction techniques. In addition, the facility is used to train utility workers in making field measurements and interpreting the results.

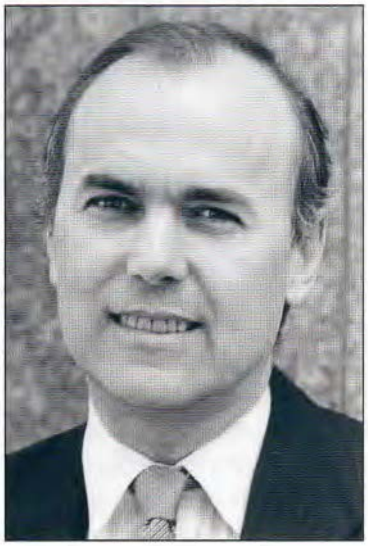
Because the facility has become a popular way to acquaint regulators, legislators, and the media with magnetic field management issues, a new Magnetic Field Educational Center is being added to enhance public communication. It will include meeting facilities, user-friendly display materials, and storyboards about the magnetic field research going on at key locations around HVTRC.

"EPRI has a long history of leadership in EMF research," concludes Karl Stahlkopf. "Now we're focusing more attention on providing service to member utilities as they mount their own field management programs. Primarily, they need more information and options for making decisions about what can be done in terms of exposure assessment and field mitigation for their customers. We're committed to helping them in this effort." ■

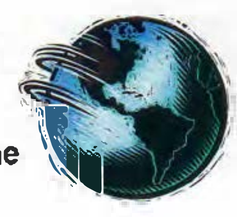
Background information for this article was provided by Karl Stahlkopf and John Dunlap, Electrical Systems Division.

BEYOND THE POLITICS OF BLAME

by Jan Beyea



Debating the world's environmental problems from hardened adversarial stances is self-defeating for both industry and the environmental community, according to Dr. Jan Beyea, chief scientist and vice president of the National Audubon Society. In a talk presented at EPRI's recent international symposium on global electrification, Beyea calls for both sides to forgo the finger pointing, discuss their real goals, and get down to the business of cooperatively crafting a vision of the future.



For the world economy and the planet's environment alike, the next 50 years represent a critical and decisive period. Fifty years from now the world's population is expected to reach a staggering 10 billion—10 billion people with aspirations to live the way we live, consume the products we consume, and use the electricity we use. During the same 50-year period, enough carbon dioxide may well be released into the atmosphere to create irreversible climate changes that could endanger the planet's environment in many ways. Can we sustain and extend the world's economic progress without causing irreparable damage to the environment?

There are those who believe we will ultimately have to choose between economic progress and environmental protection. Unfortunately, that's the sort of adversarial stance—environmentalists on one side, industrialists on the other—that has led to stalemate in the past, to the politics of blame and finger pointing. The result has often been the passage of environmental laws that are so scarred and disjointed from the blows of lobbyists on all sides that they turn out to be inadequate from an environmental point of view and unnecessarily expensive to industry and the consumer. I'd like to argue here that we need, instead, a politics of vision: a way of setting forth our shared vision of the future and the steps to get there. It's a process that will require more dialogue than argumentation, and it will call for changes not only from industry but from environmentalists as well. However, I'm convinced that at this stage in our history, it's the only way we can achieve both environmental health and economic progress.

It won't be easy. If, over the next 50 years, the rest of the world is to rise to the standard of living we enjoy today, using essentially the same technologies we have today, then global pollution levels and pressures on natural areas will increase by a factor of 5 to 10. What that means—even if we simply want to keep the world's environment as it is today—is that countries like ours will have to reduce their pollution and environmental stress by a factor of 5 to 10 within the next 50 years. If we hope for global improvement, we're going to have to do even better. And we're going to have to move rapidly, because the example we set today will shape the road taken by developing countries.

What will it take? Let's focus on the problem of global warming. Estimates of what it will cost to control emissions of CO_2 and other so-called greenhouse gases —specifically, to reduce emissions to 20% below current levels by 2015—range from slightly negative to as much as 5% of GNP. For argument's sake, let's say that 2% represents a reasonable midrange estimate. I'd like to think it does, especially given our own recent experience in renovating an old building in New York City for the National Audubon Society's new headquarters. You may have read about our venture in *Time*, *Newsweek*, or the *New Yorker*. With the help of Consolidated Edison, we were able to cut energy demand by more than 60% over the toughest codes—and we did it with a remarkable three- to five-year payback. In short, we've cut our energy consumption by more than half, we're getting great indoor air quality, and we'll be diverting 80% of our solid waste to recycling—and it has cost us virtually nothing.

So I'm optimistic that 2% represents a realistic estimate of the cost of preventing global warming. Even that's a lot of money in absolute terms, no doubt about it. But think of it in these terms: the possibility of global warming poses an uncertain future, not only for us but for the rest of the planet's species—species that cannot migrate or purchase air conditioners to adapt to global warming. Now 2% doesn't seem like an unreasonable amount to spend as insurance against that kind of uncertainty. As a percentage, it's in the right range for insurance policies. I think of a 2% reduction in GNP as equivalent to a few years' delay in material lifestyle improvement. In other words, we as Americans would be called on to live the way we lived a few years ago.

Obviously, if the real cost of addressing the global warming issue is at the high end of the range—5% of GNP instead of 2%—that's going to mean significantly greater sacrifice and a significantly more difficult political challenge. And frankly, we environmentalists are going to be in deep trouble. That's something I'm afraid too many environmentalists haven't come to understand: that we, just as much as industry, have a very real interest in keeping environmental expenditures efficient.

That's reason enough for us to seek cooperation rather than confrontation. But I think there are a number of other forces that are pushing us toward cooperation, and I just hope we are wise enough to recognize them in time. For one thing, the economic pressures faced by the United States in a more competitive world threaten to weaken the ability of government to tighten environmental laws. For another, environmental concerns are now competing with other important domestic issues, such as health care reform. Most important of all, we're simply running out of time. Projections suggest that of the some 30 million species on our planet, between 10% and 50% will be lost during the next 50 years as a result of human development. What we'll lose, along the way, is the planet's crucial biodiversity—a loss having both ethical and economic implications.

Powerful forces are pushing the electric utility industry toward partnership as well. Let's face it: environmental consciousness isn't going to go away; it's going to continue to influence both regulators and consumers. And I don't need to tell you that the constant battles we've engaged in over the past two decades have been costly. Just look at what we've been through with the issue of acid rain. Believe me, the battle over global warming could be 10 times as intense, because 10 times more dollars are at stake. It could also take 10 times longer to resolve than acid rain —120 years rather than just 12.

So we have a choice. Will we take the path of resistance, which all of us know only too well, or the path of cooperation? Let me share an experience that helped define the choice for me. I was walking in an Audubon sanctuary a few years ago when I noticed a wasp butting its head against a window. I didn't think much about it at the time. An hour later, returning, I saw the wasp still banging against that window. Then I looked down, and there was the lower part of the window completely open. All that wasp had to do was reverse its instinctive direction, go against the light, back up and go down, and it would be free to fly right out that window.

The truth is, we humans are a lot like that wasp. Certainly as an environmentalist, I've done the same thing all too many

"The result of the adversarial approach has often been the passage of environmental laws that are so scarred and disjointed from the blows of lobbyists on all sides that they turn out to be inadequate from an environmental point of view and unnecessarily expensive to industry and the consumer."

times: butting my head against impassable barriers. That's the path of resistance. But what about the other path—the path of cooperation? In recent years, a growing number of adversaries have thrown down their spears and tried a process called negotiated conflict resolution. It's not a process of compromise but rather a method for finding solutions that give both parties 80% to 90% of what they both need. Not everything, to be sure. But far more, for everyone concerned, than they would achieve by batting their heads against a wall.

How does it work? By getting both sides to sit down together and talk about their real needs and goals, not just their political positions. Representatives from both sides can then craft a completely new alternative that neither side alone was capable of discovering. Negotiated conflict resolution requires skills many of us haven't yet developed. But we can. Years ago, participating in a program with representatives of the electric utility industry, I would have been listening intensely for one reason alone: to discover weaknesses in my opponent's arguments so that when it was my turn at the podium, I could demolish the other side's case. This really amounts to enjoying the battle at the cost of finding realistic solutions. Now—maybe because I'm a little older or just have a little less testosterone—I listen for another purpose: to see if I can discover common ground.

That's what negotiated conflict resolution is all about. And it's already bringing once diametrically opposed sides together in unusual partnerships. The Environmental Defense Fund and McDonald's, for instance, have negotiated a new agreement on packaging and solid-waste handling that achieves important goals for both sides. Now EDF and General Motors have begun a dialogue that could lead to a similar agreement. And here's an example I'm particularly proud of because I was one of its chief negotiators: representatives of industry and state government—without the federal government—have agreed on a model law to bar the intentional use of the four most serious heavy metals used in packaging. It's a law that has now been passed by 14 states, and efforts are under way to expand the agreement beyond packaging to the products themselves. It's one of the most satisfying victories of my 17 years in this business. A victory, I should say, for all sides.

One of the most ambitious cooperative efforts I can point to involves Audubon, Procter & Gamble, and virtually the entire grocery industry—the Food Marketing Institute, which represents all the supermarkets in the country, and the Grocery Manufacturers of America, which includes the major U.S. corporations that sell products to supermarkets. It's a program called "Compost for Earth's Sake," and it's designed to make source-separated composting a reality. Our goal is to

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go beyond recycling, to take an additional 30% out of the waste stream and put it back to beneficial uses by composting the organic fraction and turning it into soil amendments that can be used to restore depleted agricultural land. The partnership is jointly involved in a number of programs around the country, and I can tell you that state and local governments just love it. In the end, we're going to change forever the way Americans take out the trash, and we're doing it simply by ending the stalemate over composting that has existed for many years. We're doing it, in short, by replacing the politics of blame with the new politics of vision.

Closer to home is an unprecedented partnership between the Audubon Society and the Electric Power Research Institute that led to a recent roundtable dialogue between environmental groups and the utility industry. EPRI and Audubon brought together the major players—utilities, government, and environmentalists—to craft consensus guidelines for the ecological development of biofuels. Now here's a technology that could significantly lower net carbon emissions if it's done right. But if it's done carelessly, without foresight and planning, it could be devastating to biological diversity. It's our hope, at both EPRI and Audubon, that our combined knowledge will make us wiser, that this roundtable represents a first step toward making sure biofuel technologies work for all of us. Discussions between EPRI and Audubon are already in the works to establish joint biofuel demonstration projects. And that could be just the beginning.

I think there's enormous potential for partnerships in the area of solar power, for instance. I have to admit that I feel like a tiny gadfly on the side of industry when it comes to solar power. Not long ago I started the Solar Brigade, 7000 people around the country who put little slips in their monthly utility bills asking for 10% solar within the next 10 years. Sure, we're trying to increase the pressure on utilities. But imagine how much easier it would be if both sides—utilities and environmentalists—could negotiate a cooperative path to solar right now, so that we could devote our energies to working together rather than at odds.

What negotiated conflict resolution has taught us is that you don't have to agree on everything; you can formally agree to disagree on divisive issues and still cooperate on issues of mutual interest. We've learned, too, that joint fact-finding can be extremely powerful: we can learn 10 times faster by joint fact-finding than we can separately. We can get past the inessential points of discussion and focus faster on the real differences and our common needs. Negotiated conflict resolution seems to work particularly well with opponents who are roughly evenly matched in political power. And from my own negotiating experience, I've learned that it's more effective to lay out your needs right from the beginning instead of being a poker player. That frees up negotiators to focus on new ways to get what both sides need in order to reach agreement. It helps too, I've learned from experience, to have both sides lay out not only their own vision but also a vision for their adversary.

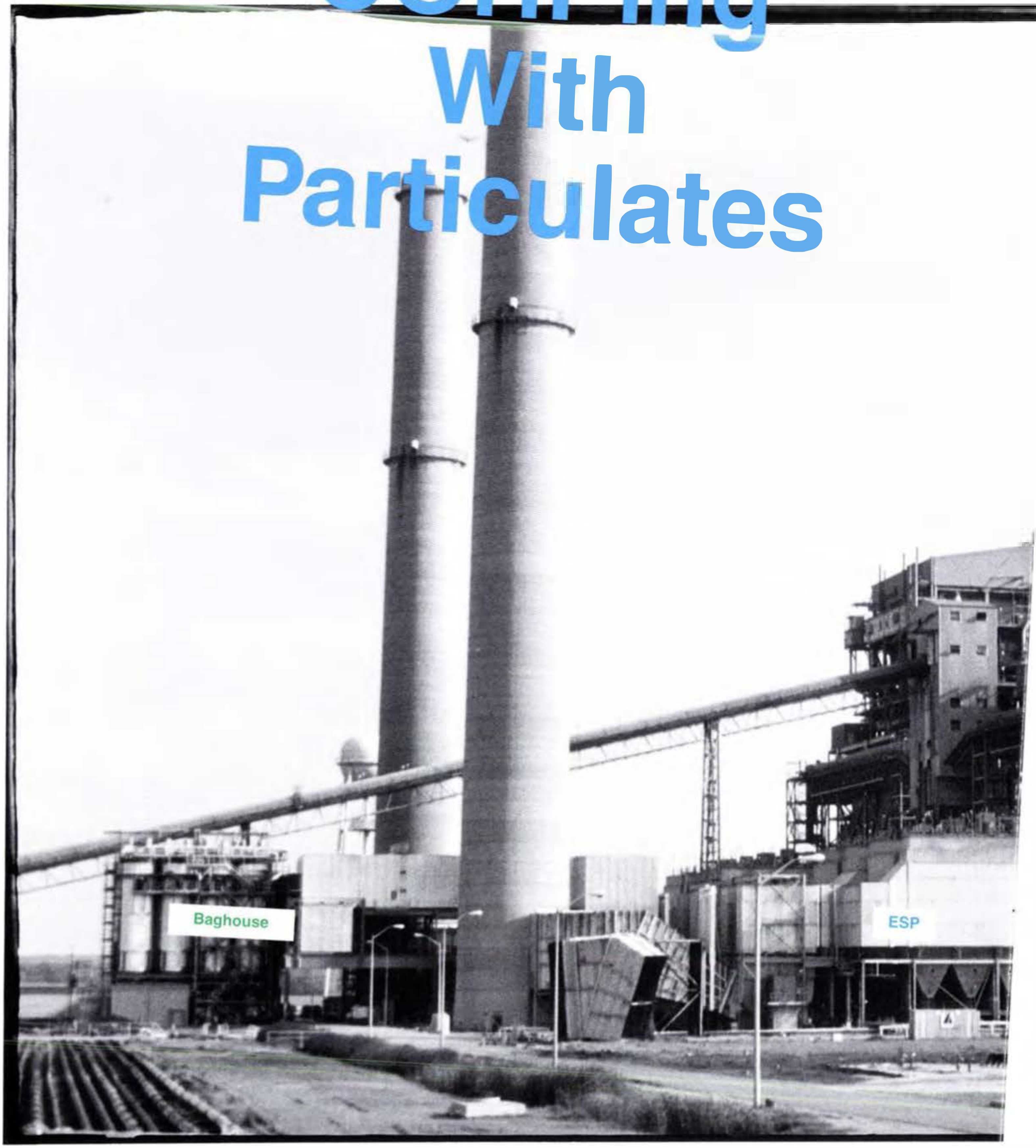
> "From my own negotiating experience, I've learned that it's more effective to lay out your needs right from the beginning instead of being a poker player. That frees up negotiators to focus on new ways to get what both sides need in order to reach agreement."

So let me conclude by trying, from the perspective of an environmentalist, to lay out a vision for the electric utility industry. What I see is a future where representatives of the industry are respected for their contributions to preserving the planet. I envision an industry whose executives are not afraid to admit that they can't predict the future and are willing to demonstrate large-scale solar facilities, for example, long before the technology is cost-effective, as a hedge against uncertainty. I see an industry that is willing to recognize its own contribution to our environmental problems and that is committed to a steady percentage reduction in pollution each year in a way that has been negotiated with environmentalists rather than imposed in a haphazard manner by regulators.

At the same time—and I think this is just as important if we are to succeed over the next 50 years—I see a future where environmentalists are wise enough to refrain from picking on utilities simply because they are an easy target. It's a future in which environmentalists are wise enough to see that a profitable electric utility will be much more willing to cooperate than an unprofitable one.

An unreachable goal? In one giant leap, perhaps. But we can travel a long way in small steps. I for one stand ready to work with this industry to find an accommodation that will keep you profitable while you do your part to clean up the mess we're all jointly making today. ■

COHPing With Particulates



THE STORY IN BRIEF

Progressing from concept to successful utility deployment in less than four years, a new technology for particulate control promises enhanced capabilities for complying with stack gas clarity standards. Called the Compact Hybrid Particulate Collector (COHPAC), this system combines two conventional control approaches—electrostatic precipitators and baghouses—in a way that offers the advantages of both while eliminating their key drawbacks. As an ESP upgrade (often necessitated by a switch to lower-sulfur coals), COHPAC readily meets emerging regulatory requirements for particulates, yet it takes up only a quarter of the space of standard, less effective fixes. A year-long commercial-scale demonstration of a COHPAC module at TU Electric has sparked utility interest both in the United States and overseas.

by Leslie Lamarre

It began four years ago as a concept entry in the project journal of Ramsay Chang, EPRI's manager for particulate control. Today it is a breakthrough environmental technology offering great promise for the utility industry. *It* is the Compact Hybrid Particulate Collector (COHPAC)—a device that removes particulates from the flue gas leaving the stacks of coal-burning power plants. As an upgrade to an existing particulate collection device, COHPAC readily meets emerging regulatory requirements for particulates yet requires only one-quarter of the space of more-conventional, and less-effective, technologies. Better still, compared with alternative particulate removal systems, it can save utilities up to 70% on capital cost and space requirements.

The COHPAC concept is fairly simple. It combines the best features of two technologies already used for particulate removal—electrostatic precipitators (ESPs) and baghouses. "Like paper clips and Post-it notes, there was nothing really profound about this idea," says Chang. "But it can certainly save utilities a lot of money." That's what TU Electric found in its demonstration of a COHPAC module equivalent to a baghouse for a 145-MW generating unit. On May 15, the COHPAC demonstration module marked one year of operation. The first utility in the industry to demonstrate a commercial-scale COHPAC installation, TU Electric plans to add, by 1996, seven more COHPAC modules to process all the flue gas leaving its Big Brown station, a 1150-MW lignite-burning plant consisting of two 575-MW generators.

Chang had just joined EPRI when he wrote the journal entry about his concept for COHPAC on December 15, 1988. "At the time we were focused—as we still are today—on the fact that competition is getting keener for utilities and that, in order for them to continue to prosper, we not only have to develop more-efficient devices but also must make them cheaper. The idea was to find a way utilities could do things smaller and simpler." At the same time, work on amendments to the federal Clean Air Act (ultimately passed in December 1990) was well under way, and it was clear that more-stringent emissions reduction requirements were soon to come.

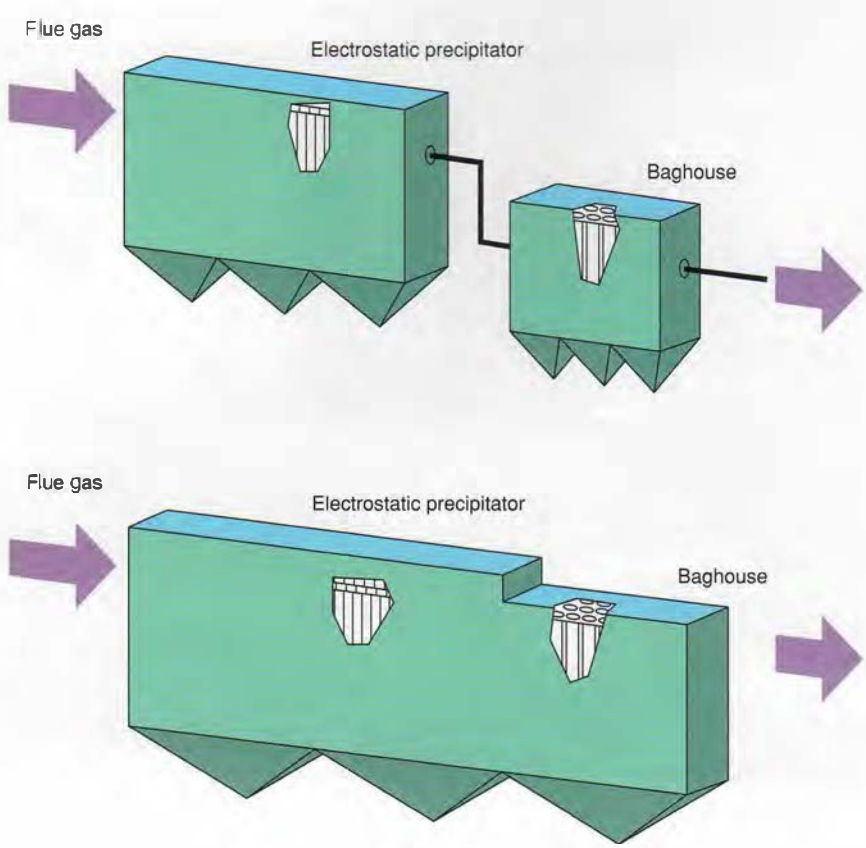
While the 1990 Clean Air Act Amendments do not regulate particulate emissions directly, they do impose more-stringent limits on the discharge of sulfur dioxide (SO_2) and nitrogen oxides into the atmosphere. And in many cases, meeting the SO_2 requirements hinders the particulate removal process. This is because a number of utilities have chosen to reduce SO_2 emissions by switching to lower-sulfur coal or by adding SO_2 sorbents upstream from their ESPs. Both these SO_2 control options have a tendency to degrade ESP performance because they increase the volume of fly ash produced and the electrical resistivity of the fly ash.

Best of both worlds

Most utilities in this country rely on ESPs to remove particulates. Housed in giant chambers, these devices electrically charge the fly ash in the gas stream before it leaves a generating plant. Once charged, the fly ash particles are attracted to a series of giant plates inside the chamber. A rapping device periodically vibrates the plates so that the particles accumulated on them fall to the bottom of the chamber and through hoppers for disposal.

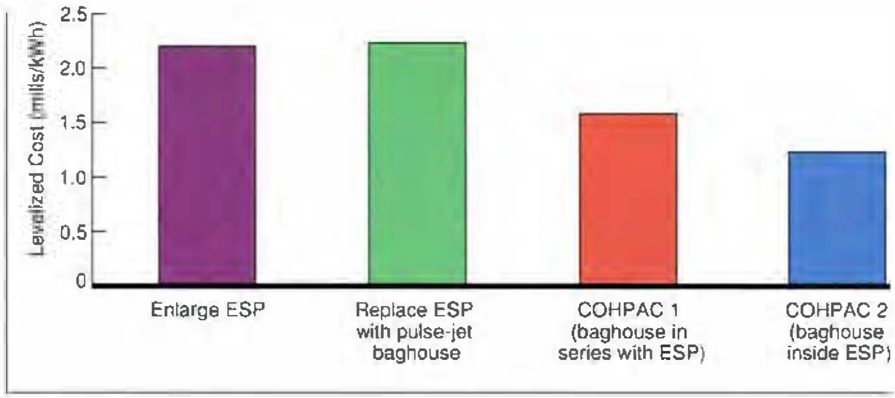
When used with relatively high sulfur coal, ESPs can meet the opacity standards for flue gas emitted from power plant stacks. (These standards govern the amount of fly ash emissions in the flue gas. They are typically set at 20–30% opacity.) In order to perform well with the highly resis-

The COHPAC Concept There are two ways to configure the Compact Hybrid Particulate Collector developed and patented by EPRI. The first, which has been employed successfully on a commercial scale, is to add a baghouse in series with an existing electrostatic precipitator. The second method, which has not yet been demonstrated, involves removing a portion of an existing ESP to make room for a baghouse inside the ESP chamber. In each configuration, the flue gas flows first through the precipitator and then through the baghouse.



tant fly ash produced by low-sulfur coal, however, these devices must be very large, which makes them costly to build. Also, in many cases they are not as effective in removing fine particulates from flue gas as baghouse technology is.

Employed widely in a variety of particulate removal applications in the United States and overseas, baghouses work like giant vacuum cleaners. The technology is literally a house of bags, similar to those used in a vacuum cleaner. Made from a variety of synthetic materials, such as fiberglass, Nomex, Ryton, and Teflon, the bags in a baghouse filter the airstream that flows through, removing 99.9% of the particulates in the gas stream. The fly ash collects on the surface of the bags. Generally, the effectiveness of baghouses does not vary with coal type or fly ash properties.



Top Performer As this graph indicates, COHPAC technology is the most cost-effective of the available options for improving the performance of a small ESP. The figures shown assume the use of a relatively low sulfur coal and the removal of enough particulate matter from flue gas to achieve an opacity level of less than 5%. The cost for the second COHPAC option, in which the baghouse is placed inside the ESP, is an estimate only, since this configuration has not been demonstrated.

In a conventional baghouse, the bags are cleaned periodically by reversing the flow of the air through the bags, knocking the dust into a hopper below. The more advanced, pulse-jet baghouse does not reverse the airflow through the bags to clean the ash but emits strong pulses of air, which knock the ash into the hopper. The main drawback of baghouse technology is that pressure drop increases significantly as the particulate matter accumulates on the bag surface. To minimize pressure loss, it is necessary to limit the amount of flue gas processed by each filter bag; as a result, baghouses tend to be very large.

The COHPAC concept developed by Chang combines ESP and baghouse technologies, offering the best of both options minus the key drawbacks. In other words, COHPAC achieves the high particulate removal capability of baghouses without the need for a very large device to avoid a pressure loss problem. In a COHPAC system, the air leaving a power plant flows first through an ESP. The gas stream, containing the particulates that weren't sifted out by the ESP, then flows through a baghouse. Because the ESP has already significantly reduced the amount of particulates and has charged any remaining particles—causing them to repel one another, so they do not clog the pores in the bag material—air can pass through the filter bags of a COHPAC system at four to eight times the velocity of the air in a conventional baghouse. The result is a greater than fourfold increase in the amount of flue gas that can be processed by a baghouse and, in turn, a proportionate reduction in size and cost.

Technology development

Shortly after Chang proposed the COHPAC idea, EPRI conducted a patent search and discovered that no one had filed a patent for such a concept. "It was hard to believe that no one had thought of this before—it seemed so simple," recalls Chang. Then late in 1989, EPRI researchers tested the idea, using flue gas from a coal-fired boiler. As Chang had theorized, the process successfully removed a high percentage of particulates at very high filtration rates.

Soon TU Electric stepped forward to field-test, with EPRI, a 1-MW COHPAC unit at its Big Brown plant. Built in the early 1970s, Big Brown predates the federal New Source Performance Standards, which regulate particulates and other emissions. But the state of Texas required adherence to a 30% opacity limit for pre-NSPS units. The two Big Brown units were equipped with very small precipitators. Under most operating conditions, these precipitators controlled stack opacity to below 30%; however, there were instances when unit load had to be reduced to maintain opacity compliance. In response, TU Electric upgraded and modified the precipitators and installed fly ash conditioning systems—actions that alleviated but did not resolve the problem.

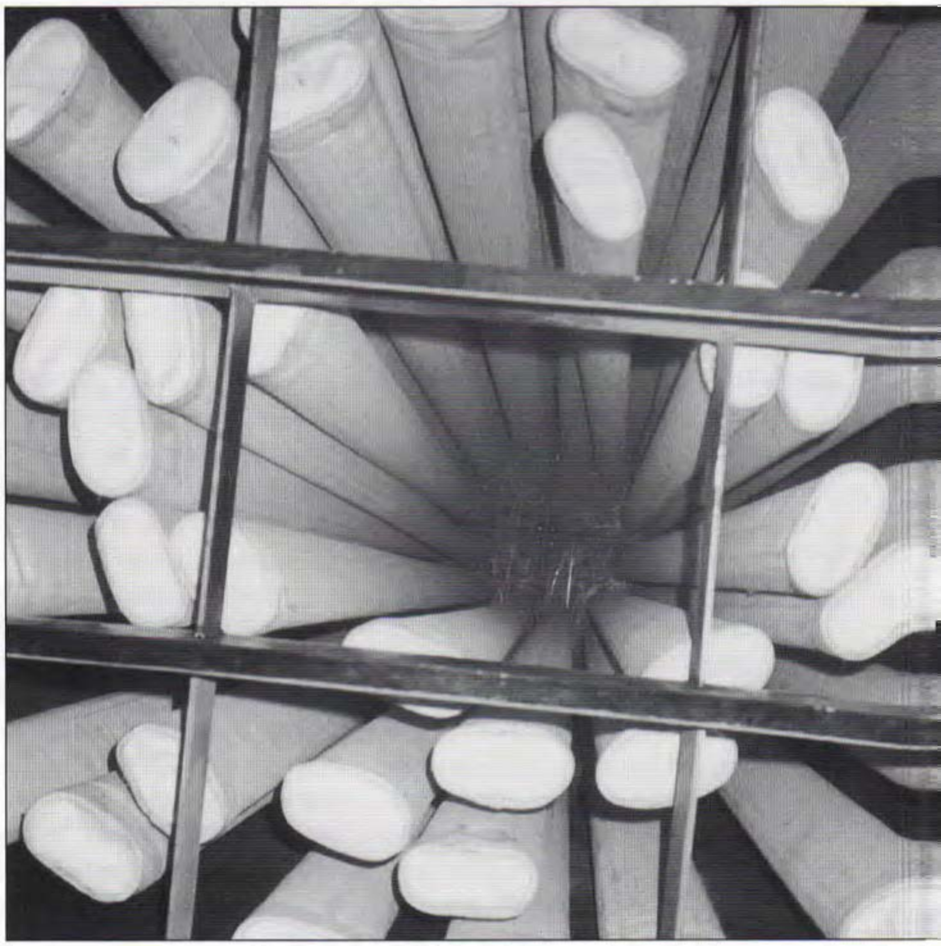
In December 1990, the utility reached an agreement with the Texas Air Control Board that it would adhere to a more stringent limit of 20% opacity on one Big Brown unit by the end of 1995 and on the second unit by mid-1996. EPRI's development of the COHPAC concept had come just in time. With positive results from the 1-MW test unit at Big Brown, TU Electric decided to demonstrate a commercial-sized COHPAC unit.

"We had a real problem to solve and a deadline to do it," recalls Ben Brown, a project engineer in TU Electric's Advanced Generation Engineering Department. "The technology had progressed far enough at the pilot scale that we felt confident in moving to the next step. Also, we could see that the rewards were substantial." Other alternatives TU Electric considered included replacing the existing precipitator, adding a second precipitator in series, and adding a standard baghouse (which operates with lower gas velocities than does a COHPAC baghouse). Initial cost comparisons showed that these alternatives would be 30–50% more expensive than COHPAC and would occupy about four times the space COHPAC would require.

A House of Bags The baghouse element of a COHPAC unit functions much like a vacuum cleaner; interior bags filter out particulate matter from the flue gas as it rushes through. TU Electric's 145-MW COHPAC unit contains 2500 bags, each about 6 inches in diameter and 20 feet long. The bags in a baghouse can be made from a variety of synthetic materials, such as fiberglass, Nomex, Ryton, and Teflon.

Installing bags from the top of a COHPAC baghouse.

Each COHPAC bag is 20 feet long.



Looking up from the hopper at a pilot-scale COHPAC baghouse.

Inspecting particulate dust collected on a COHPAC bag.

Design of the COHPAC unit began in March 1991. Three months later, EPRI acquired a patent on the concept. By May 1992 the TU Electric unit, supplied by Research Cottrell, was operating. "The quick turnaround time benefited from a dedicated TU Electric team and the assistance of EPRI project manager Walt Piulle," notes Chang. In the past year the COHPAC module has yielded positive results, coming well within the project team's goal of achieving less than 5% opacity at the exit from the module. TU Electric considers the demonstration module to be a permanent installation and plans to add seven equivalent-sized COHPAC modules to comply with the state mandate on opacity. EPRI will continue to monitor the initial module for the remainder of the year.

Interest from others

While other utilities are cautious about moving forward with COHPAC at this stage, many have expressed an interest in the technology. "We've had several inquiries from day one," says Brown. "Now that the industry knows about the success of the demonstration, we're going to see even more interest. This technology may become the answer for tough particulate control problems for retrofits as well as for future coal-fired generating units."

According to Chang, there's been interest in COHPAC technology overseas as well. A utility in Australia has picked up on the COHPAC concept and built two 1-MW demonstration units based on the EPRI patent. Meanwhile in the United States, says Chang, "utilities have been waiting to see what the results of the TU Electric demonstration will be."

Some U.S. utilities, including Alabama Power (in conjunction with Southern Company Services) and Duke Power, are beginning to take action through pilot studies similar to TU Electric's first-phase, 1-MW application. And six other utilities, which intend to switch to low-sulfur coal to comply with the Clean Air Act Amendments, have undertaken engineering designs to determine how COHPAC units would respond. Industry confidence has been boosted not only by the success of TU Electric's experience but by the fact that manufacturers are already offering warranties on COHPAC technology.

TU Electric implemented COHPAC by adding a baghouse to an existing precipitator, but there may be a second way to retrofit existing particulate removal systems—by removing a portion of an existing ESP and putting the baghouse inside the ESP chamber. (Last year EPRI obtained a patent on this concept.) In either case, air flows first through the precipitator and then through the baghouse. The second option, which has not yet been demonstrated, would be even less expensive to build, Chang says.

Regulation driven

Chang suspects that more utilities will show an interest in COHPAC technology as regulatory pressures to improve air quality increase. "Utilities must be constantly thinking ahead, since there's so much activity these days in the regulatory arena on clean air issues," says Chang. "They want to get a head start on anything they might be required to do."

With this in mind, utility advisors have encouraged EPRI researchers to assess the potential benefits of using COHPAC to address an environmental issue that is not now subject to regulation—the presence of traces of potentially hazardous chemical species in flue gas emitted by fossil-fired power plants. A federal study of these species, mandated by the Clean Air Act Amendments, is now under way; results are expected within two years. In the event that some of these trace species are regulated by the Environmental Protection Agency, COHPAC may offer the most cost-effective means of filtering them out. Trace chemical species exist in both particulate and vapor form. If these species are limited to lower levels than are typically released by power plants with existing particulate controls, the increased efficiency offered by COHPAC may be needed to capture a greater percentage of the particulate-form species. At the same time, COHPAC's configuration makes it easier to use sorbents, which may be able to capture the vapor species for disposal. In a COHPAC system, the sorbent can be injected after the precipitator and before the baghouse. This allows for the separation of large portions of the potentially hazardous chemical species from the bulk of the fly ash, enabling easier disposal and even recycling.

Chang points out that while COHPAC offers an attractive option for many applications, it is not appropriate for every case. For instance, in situations where an ESP does not require a significant upgrade, COHPAC may not be the best answer. Instead, the utility may find that adding chemicals to condition the flue gas or using one of several upgrade options developed by EPRI (as described in the *EPRI Journal*, March 1989, p. 42) is a less expensive alternative.

Still, for many utilities COHPAC may prove to be the right answer at the right time. "COHPAC falls right in line with utilities' priorities today," says Chang. "They are looking at cheaper ways to stay alive. Cost-competitiveness and cost-effectiveness are their concerns now." ■

Background information for this article was provided by Ramsay Chang, Environment Division

Robert Bozzone

Alloy of Metallurgy and Management

by Ralph Whitaker

Fresh out of Rensselaer Polytechnic Institute with a degree in metallurgy, Robert Bozzone went to work for Allegheny Ludlum Corporation in June 1955 at the age of 22. He's been with the company ever since--38 years.

But it's not the only place he's ever worked. Describing the 10 years before he joined Allegheny Ludlum, he says, "I threw newspapers, I worked after school in a grocery store, I stoked a neighbor's coal furnace, I mowed lawns. I started at a jewelry store when I was 12, and I never stopped. I was always employed."

With his metallurgy degree and his motivation, Bozzone moved right along in the stainless steel business. He has been the president of Allegheny Ludlum since 1985 and its chief executive officer since 1990. Understandably, he's selective about his side chores today, but one responsibility he chose to accept was membership on EPRI's Advisory Council.

Since 1990, Bozzone has met periodically with some two dozen advisory colleagues drawn from positions of vantage outside the power industry. Ten Council members are state utility regulatory commissioners recommended by their national professional association; the others are individually invited by EPRI from such fields as law, medicine, education, labor, conservation, manufacturing, and finance. Deliberating as a whole group and in topical subcouncils, they bring varied perceptions of the public need and interest to bear in their review of EPRI's research priorities and programs.

Entering the steel business right out of college, Bozzone gained visibility in the hot field of specialty alloys and soon found a career in business management. Now president of Allegheny Ludlum and also a member of EPRI's Advisory Council, Bozzone gives his industry-tempered perspective on the issues of economic realism, international business opportunity, and the value of research.

Growing up

Some of Bozzone's familiarity with electric utilities goes back to his childhood in Glens Falls, New York, about 50 miles north of Albany. "My father was a distribution service supervisor for Niagara Mohawk Power Corporation, and my mother had been a secretary there, so I grew up in a utility-oriented home environment."

For Bob Bozzone and his younger brother, Bill, Glens Falls was almost perfect, situated between the resort areas of Saratoga Springs and Lake George. "In one of my high school years, *Look* magazine named Glens Falls its all-American city. The high school was just the right size. Big enough that it had all the facilities. Small enough that you could be a player. You could take some satisfaction from the things you did, the contributions you made."

But Bozzone's strongest memory centers on Governors Island in New York harbor. "I had an uncle stationed at First Army headquarters there, so I got to visit during the latter years of World War II. I'd spend a month or six weeks during the summer caddying on the nine-hole golf course. The caddy corps was seven Italian prisoners of war and me! I was their bambino!" Bozzone spoke no Italian, and the POWs spoke little English, but they found ways to communicate, and he became their "agent" when occasional tips funded a trip to the post exchange for candy bars.

Those summers were valuable in other ways. Bozzone's uncle and aunt introduced him to the subway, and after that his own nickels regularly took him to Yankee Stadium, the Polo Grounds, or Ebbets Field for the ball games. "When I look at what has shaped me," Bozzone says today, "all that experience was certainly a confidence builder. I was dealing with issues of independence and selfreliance as a relatively young person."

Confidence must have been a factor in Bozzone's early and energetic commitment to work. But he also remembers the early realization that a college education would be expensive—"$750 or something like that for a year at Rensselaer in those days. A lot of money."

And he remembers his father's frequent mention that public utilities—Niagara Mohawk among them—offered stable employment; that, and a pension plan. "They put food on the table, but they didn't make anybody rich. I felt I had to contribute. So I had a lot of jobs."

Bozzone's own business is the work that comes most clearly to his mind. It began with mowing lawns. "But when I got more work than I could handle, I got some friends and organized them and scheduled them. I had two or three guys working for me." Chuckling at the informality of those days, Bozzone adds, "No paperwork, no reports, and I didn't have to pay Social Security taxes."

It was a nose-to-the-grindstone existence, but most of the time Bozzone was still able to take on extracurricular activities. He was in Scouting for a while—a Catholic who followed his friends to a troop sponsored by the Presbyterian church. And he later passed up the Catholic high school because the public school offered a better math and science education. His parents supported that decision, but the family pastor continued to suffer minor discomfort, partly because Bozzone was so visible. "I was president of the student council, and I ran the YMCA youth social activities—even though at that time Catholics just didn't associate with the Y."

How about his schoolwork? Bozzone is offhand. "I was comfortable with it," he says, "and in high school I did have very high grades—third in my class of 160 or so. But when it came to college, things got much more difficult." Still the baseball lover of his Governors Island summers, Bozzone decided to play baseball in college, as he had in high school. But after one season on the team, he recalls, "I realized I couldn't carry it there."

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Bozzone's direction in college was a product of both encouragement and aptitude. "My dad had only an eighth-grade education. He admired the engineers he worked with at Niagara Mohawk and thought theirs was the avenue his son should take. I happened to be the son with some skill in science and math, so I was directed along those lines."

Getting down to business

When Bozzone started at Rensselaer, he and his classmates wondered whether they would be caught up in the Korean War before graduation. Joining the Air Force ROTC essentially guaranteed that Bozzone would get to finish college, but after two years of drills, he failed a vision test. "It was devastating, because I wanted to fly. By then I was excited about it," Bozzone says. He also remembers his mixed emotions—and the irony of the situation—when he was subsequently deferred from service because he was an engineering student.

Three summers with Niagara Mohawk were Bozzone's main extracurricular activity. "I worked on a right-of-way gang, dropping trees and clearing for power lines in the mountains. On another project we took out old light standards in downtown Albany. And I ran a jackhammer, putting in underground lines. I was in better shape than I've been since."

By 1955 Bozzone was definitely in good shape for the professional world. As he puts it, "Rensselaer had the largest graduating class of metallurgists in the country, and we were in demand. It was a year for metallurgists. I had more than a dozen job offers, and Allegheny Ludlum wasn't the top. But I wanted a production job—out on the plant floor, out where things were made—and that's what they promised me."

Bozzone's insistent manner in describing the memory is soon explained. Joining the Allegheny Ludlum training program at Brackenridge, Pennsylvania, barely two weeks after graduation, he learned that all new metallurgists were slated for two years in the research laboratory. Bozzone's response was immediate; he announced he was quitting because the conditions of employment had been changed. The training coordinator was taken aback, and so was Allegheny Ludlum's vice president and technical director, who was persuaded to talk with Bozzone.

The conflict of nearly 40 years ago reappears as Bozzone reenacts his surprisingly confident response that day. "I told him, 'I know myself. I can't work two years in research. I've got to be in the mill, where the action is. But I have no ill feelings. Other people offered me jobs out in their plants. I'll see if I can reactivate those offers.'

"It must have seemed I was challenging the technical director's authority. 'We know what's best for you,' he said. 'Trust us. This is the way it has to be. If not, good-bye.' I said fine and went to tell the trainer that I'd pack up and head home."

But the next morning, as Bozzone was making flight reservations, the trainer called. He had appealed on Bozzone's behalf: there was an opening in production metallurgy at the nearby Leechburg, Pennsylvania, plant, and Bozzone could interview for it that morning. "I went up.

I met the guy. We hit it off. And that's how I got going. But I guess I can say I quit the company two days after I arrived!"

The tale warms Bozzone to a thoughtful conclusion. He is proud, he says, of the 22-year-old "who had the gumption to make that kind of a call." But beyond that, he adds, is a lesson he has carried into his leadership years. "I look for people who are independent thinkers, willing to speak their piece. They're the ones I like to see on my management team."

And management, of course, was Bozzone's goal from the very beginning, even back in the lawn-mowing days. In his own mind at least, he immediately put himself on the management track at Allegheny Ludlum. "I wanted to move through the technical side, understand the process, and then do something about managing it."

Becoming visible

Considering the equivocal circumstances of his hiring at Allegheny Ludlum, Bozzone is grateful for two instances of good fortune that soon followed. First, he was assigned to a special-metals group overseeing the processing of titanium, brand-new at the time and just beginning to be used in military aircraft. He was in a high-visibility area, and within a year Bozzone found himself with a security clearance and involved in work for the refueling of the nuclear submarine *Nautilus*. "We were making zirconium alloys for the reactor fuel rods, and it was great experience. Learning about stainless back in the research lab, or even working on the mill floor, my contemporaries didn't have the same exposure. I got to hear Admiral Rickover lecture the group —and hear him chew people out for the problems they were having."

The Allegheny Ludlum management watched the special-metals group very closely because the alloys under its wing were seen to be the future of the company. A consequent business move by Allegheny Ludlum was Bozzone's second bit of good fortune. It was a joint venture with National Lead called Titanium Metals Corporation (Timet), which was headquartered in New York but relied on Allegheny Ludlum's Leechburg plant for the rising volume of finished titanium going into aircraft.

"Timet had no infrastructure at the plant," Bozzone explains, "so our technical group accepted the titanium orders and did all the scheduling. We did more than just metallurgy; we became the business managers for titanium. All of a sudden I was into production planning and production control."

Working closely with his Allegheny Ludlum counterparts in stainless steel production control, Bozzone became familiar to the managers of that established activity. In particular, he says, "the works manager got to know me very well because I was the guy running all this high-visibility stuff through his plant." The relationship was pivotal, and when asked about individuals who had influenced his career, Bozzone is quick to cite that works manager, "who picked me out of the laboratory at Leechburg to become a production planner—his assistant, at first—so I could get a broader perspective of management."

That was in 1960, five years after Bozzone had arrived at Allegheny Ludlum. Four years later he would officially become a production control manager, and in seven more years—1971—a division manager with control of production at two merged plants. Also, he was moving beyond special metals into stainless steel as well. In the telling, it's a slow progression, but Bozzone acknowledges that he was on a distinctly fast track. It certainly became a strenuous track as the 1970s approached and the steel industry of the United States began to rust.

In fact, specialty steels were the first to feel the threat of imports, Bozzone says, because producers abroad first targeted the high-margin steel grades—stainless rather than carbon. "We recognized that we had to accelerate our efforts in quality if we were to compete. And we had to go after cost reduction in a ferocious way. We were pushing heavily on what would be called total quality management today—before anyone else in our industry had even thought about it."

If Bozzone sounds proprietary on the point, it's because just two people have headed Allegheny Ludlum's steel business from then to the present—Richard Simmons, now board chairman, and himself. Bozzone says simply, "He and I formed a team, and we began to change the steel operation. Things as mundane as profit-centered plants. We made each plant a cost center; profits come at a different level."

He goes on, "Our changes weren't technical. We were changing the management style. And we went through systems

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changes—for instance, we introduced data processing well ahead of any of the integrated producers." Bozzone attributes much of the insight to Simmons, who recognized what was needed from problems he had seen in his earlier work for a carbon steel company. As a result, Bozzone concludes emphatically, "I'd say we've been five to seven years ahead of other companies. We survived because we acted more quickly."

Perhaps because of the difficulties of the 1970s, the old-line Allegheny Ludlum was becoming a conglomerate, Allegheny International, buying companies and adding product lines for the consumer market—garden tools and machinery, golf club shafts, even matches. There came a time, early in 1980, when the steel business suddenly was put up for sale. "For the rest of that year," says Bozzone, "I ran the business and Dick Simmons ran around looking for someone who wanted to buy a specialty steel company."

Living two lives

By 1980 Robert Bozzone had been with Allegheny Ludlum for 25 years. His account of those years is so animated that one might conclude that he lived and breathed stainless steel. Indeed, even his family life began at Allegheny Ludlum: Irene Bozzone had been a secretary in the engineering department at Leechburg. "We were married in 1959, the year of the big steel strike," Bozzone says, but he quickly adds, "Irene hates to hear me say that. She says, 'Think of it as the year we got married.'"

Home and family became as spirited and urgent an existence as Allegheny Ludlum for the Bozzones. A daughter and two sons were born by 1967, and Bozzone focuses enthusiastically on his wife's dedication to them during a time when he was often preoccupied. But sports and vacations involved all of them, and it's only a small slip of the tongue when Bozzone says, "I pushed—no!—I led the children into Junior Achievement because I thought they ought to have business sense." He recounts that Mary Jo won a regional title in JA, while Mike and, later, Mark were area representatives to JA national meetings.

Jumping ahead to the present, Bozzone sums up his offspring's achievements. "We've got a retailer—a senior buyer, actually—who was married a few years ago and has now retired to start her family. And a son, Mike, with his own insurance agency and a half dozen people. He had all kinds of jobs as a kid, as I did; he was buying stocks when he was a junior in high school. Mark, 27 and the youngest, has been a banker for three years now and is moving up through the loan department."

But while his children were still in their teens, Bozzone's company was at an executive crossroads. What was going to become of the Allegheny Ludlum steel business? As 1980 wound down to its last two months, Simmons and Bozzone could finally say they had a deal—with Clint Murchison, who then owned the Dallas Cowboys. They were going to use a brand-new concept called a leveraged buyout. "We got to the altar the week before Christmas, but Murchison couldn't free up his equity. We had one week to find a white knight."

Amazingly, a Pittsburgh-area man came forward and in one week made it possible for the Allegheny Ludlum steel business to go private in what was then the second-largest leveraged buyout in history—$195 million. Recalling the swiftly completed transaction, Bozzone shakes his head over the memory of "a little fledgling buyout firm called KKR" that wasn't big enough to handle it. That was Kohlberg Kravis Roberts, now known for arranging the 1989 RJR Nabisco buyout at $25 billion.

In an already-embattled steel market, says Bozzone, the newly private Allegheny Ludlum now had other constraints. "Going into 1981, interest rates were 21%," he points out. "We tightened down. We managed for cash flow; we were cash flow, cash flow every month." But the company was so successful that after six years its backer asked to be bought out. His sizable investment of preferred stock was repaid dollar for dollar, but for his $4 million of equity he took away $160 million. In Bozzone's understatement, "He was a very happy fellow."

Having meanwhile been releveraged, as well as having borrowed money to pay off its backer, Allegheny Ludlum went public again in 1987. Its position today is an obvious source of pride to Bozzone. "We've never had a losing quarter," he says flatly. "And that's a record in the steel business."

Bozzone looks back over his company life. "Starting out as a metallurgist looking for a job out of college, I never expected to live through something like a leveraged buyout. But all these things have been very enlightening. There were days when the banks were looking for that money at 21% and we weren't sure we could make it. Now I can honestly say it's been fun." He pauses. "But it wasn't *always* fun."

Considering the intensity of Bozzone's major engagements with work and family, it's no wonder that he is careful in choosing his community and professional advisory roles. "I'm selective," he says forthrightly. "I chair a Federal Reserve bank board in Pittsburgh, a branch of the Cleveland bank. I've been asked to chair the Cleveland board, but it's too much time.

The Salvation Army, though, is another story. Bozzone feels very strongly about the spectrum of its service and its effectiveness. He's been active on the army's behalf for five years and now cochairs a two-year, $14 million capital campaign. "We've got $6 million raised, and we're looking for the other $8 million," he reports.

Advising EPRI

Duquesne Light Company and EPRI are related organizations that claim Robert Bozzone's advisory interest, but for different reasons. Allegheny Ludlum is a large supplier of electrical steels—they account for 17% of its sales—so utilities are a familiar market, and Bozzone has served as a director of the Pittsburgh-based utility since 1990.

But his interest in EPRI springs mostly from his aggressive attitude toward research and development. "We spend 3% of our sales dollars on R&D," Bozzone points out, "and we've never deviated from that. Even when we were paying 21% interest in 1980, we didn't cut the research budget." Indeed, Allegheny Ludlum has done research for EPRI on transverse flux induction heating, and one of its alloys is used in the amorphous metal that Allied Signal developed under EPRI sponsorship for low-loss transformer cores. "So when I was asked to serve on the Advisory Council, my answer was definitely yes," says Bozzone.

"There must be winners and losers in business. When we start to tamper with the system and don't let the losers become losers, that's a problem. Winners should win big, and losers should disappear from the scene and move on."

Asked about current issues that engage the Council, Bozzone draws from his interest in R&D and from his background as a utility director. "Duquesne and General Public Utilities have proposed a transmission line across Pennsylvania in order to take advantage of unused generating capacity in the western part of the state. But there's a problem—just three little letters, EMF." He therefore welcomes EPRI's effort to learn if and how electric and magnetic fields affect human health. "It's a big help to the power companies, of course, but EPRI's objectivity means data that can help the environmental community too."

Objectivity is one of EPRI's main attributes, in Bozzone's opinion, and he links it with the strategic question of how EPRI can best further its technology leadership position on behalf of U.S. utilities. One of the difficulties he sees is that short-term political considerations can preempt the best science. By way of example, Bozzone points out, "The 1990 Clean Air Act Amendments focus on sulfur dioxide and do nothing about carbon dioxide, which is going to be an area of concern in the future. Principally aware of acid rain, legislators acted without having the comprehensive technological databank they really needed." As a result, he concludes, the remedial actions written into current law are probably not what would best treat the larger problem of both SO_2 and CO_2. But he sees EPRI as getting ahead of the curve on EMF, and that pleases him. "We're going to be positioned to guide the process and not have it overwhelm us."

That observation leads him to a clear endorsement of EPRI's executive management attitudes and approaches. "I see a sense of"—Bozzone searches for the right phrase—"economic realism that I think is extremely important. EPRI and its staff are very focused on the scientific aspects of their work, but I'm encouraged that they don't lose sight of the ultimate economic impact. Being an arm of the utility industry, they have a better sense of that need than others. EPRI is more real-world. Duquesne Light, for example, is using specific operating recommendations developed by EPRI. These are detailed, with experimental data from work at other utilities. I think EPRI is very proactive."

Freeing the enterprisers

Future patterns of the electric power business are a standing topic of conjecture and prediction among EPRI advisors, management, and member utilities. Hopes and fears sometimes are expressed too—but not by Bozzone. He sees opportunities.

Change is bringing competition, as new business and technological realities cause utility service territory boundaries to become blurred. Independent power producers are becoming a factor. Allegheny

Ludlum is already seeing the consequences in its gas utility service—with a choice of three suppliers. "We buy our gas from the one that offers us the lowest cost," says Bozzone, "and I think this is a window on electric utility competition down the road."

From long experience as a specialty product marketer, he is quick to notice specialized electricity service, niche markets, and so on. And he's especially impressed by some of the early ventures abroad by electric utility energy and service subsidiaries. Developing nations are clearly a market for more than the hardware for power generation and delivery. "They need people to show them how to manage fuel purchases, operate at lowest cost, schedule maintenance economically, and those kinds of things. They need the expertise that comes from having operated plants. Shame on us if we're not out there selling it!"

Bozzone cements his argument with two observations from Allegheny Ludlum's experience. "We do it in steel," he says. "We've taught Romanians and Poles how to make electrical steel. We've sold electrical-steel-making technology in Korea. We have a 10-year arrangement there, with visits back and forth to exchange data."

But even more telling is Bozzone's example of a chromium alloy producer in India—an Allegheny Ludlum supplier—that can operate only 6 hours a day because there isn't enough electric power. "India obviously needs work on its generation and distribution infrastructure. Why not sell services there? As we look at the future, I think U.S. utilities will be reaching out beyond their own boundaries. EPRI's already moving in somewhat the same direction, with its international affiliates."

Bozzone's words about business can hardly speak as loudly as his actions in business. In fact, he is soft-spoken, and his enthusiasm comes across in gentle insistence more than in colorful hyperbole. He has convictions about ethics, for example. "We run a very ethical company, and we feel very good about that," says Bozzone, "but it's disturbing to me that, in the eyes of so many children, businessmen are unethical and money grubbing. In too many cases they are, but, of course, the good guys don't get a lot of attention. I feel strongly that business overall needs to operate ethically—and take steps to build its image."

His philosophy of the free enterprise system is equally straightforward. "There must be winners and losers in business. When we start to tamper with the system and don't let the losers become losers, that's a problem. Winners should win big, and losers should disappear from the scene and move on."

Government at various levels is too likely to do the tampering, Bozzone believes. But he traces the problem to what he calls "a loss of contact" by bureaucrats and legislators rather than to any ideological failing. To explain, he recounts a time he was with the late Pennsylvania senator John Heinz when a concrete truck drove by, its drum slowly revolving. Heinz volunteered that this image always excited him. Why? Because as a young man he had worked briefly in industrial sales, and he could never forget the commission he had earned on his first sale of a concrete mixer. "That's my kind of politician," Bozzone concludes. "He never lost touch."

Bozzone works hard to stay in touch. "We run our company that way. I go to the plants—I know them inside out. I think it's the only way to manage." He knows he relates well to people, so in the phrase popularized by management consultant Tom Peters, Bozzone manages by walking around.

He inevitably uses those occasions for team building. "I love to see participative management. We're very active in this. I think breadth of management skill is what allows a company to survive. We encourage our people to participate, and I get much greater joy in seeing my team succeed than if I hit the home run."

Revitalizing the economy

Asked about the main issues that he and his team face today, Bozzone quickly names two. "How do we grow? How do we remain globally competitive?" He acknowledges the happy circumstance that new technologies spawn industrial processes that require extreme operating environments and consequently increase the demand for durable stainless alloys. He obviously wants Allegheny Ludlum to be at the forefront, and he can't resist a plug: "People are quality-conscious. Stainless will last forever. First cost is last cost."

At the national level, Bozzone sees economic growth as a need to be met by a combination of actions. "We have to get our fiscal house in order; we must become financially prudent. I also think education is extremely important. Labor Secretary Robert Reich is right about educating our work force, training workers to make sure they have globally competitive skills. And I think we've grown away from the production of goods; I'd like to see actions taken to strengthen the manufacturing sector."

Most of all, Bozzone emphasizes "getting on a faster track." His career and his company over the last 38 years illustrate and validate what he has to say. Simply reflecting the change in the world, he goes on, isn't sufficient. "We talk at Allegheny Ludlum about velocity of change. You've got to change at a velocity that puts you ahead of the pack. The organization that changes most rapidly is the winner." ■


STAHLKOPF


DUNLAP


BEYEA


CHANG

Managing Magnetic Fields (page 6) was written by science writer John Douglas with information from members of EPRI's Electrical Systems Division.

Karl Stahlkopf became the director of the Electrical Systems Division early in 1992. He previously directed the Nuclear Power Division's Safety and Reliability Department and from 1980 to 1989 headed that division's Systems and Materials Department. Stahlkopf came to EPRI in 1973 after seven years in the Navy, where he specialized in nuclear propulsion. A University of Wisconsin graduate in electrical engineering, he also holds MS and PhD degrees in nuclear engineering from the University of California at Berkeley.

John Dunlap has been manager of the Electrical Systems Division's magnetic fields research since 1991, and he also worked in the EMF area at Florida Power & Light from 1987 to 1990. Dunlap had been employed by both organizations previously, having worked in EPRI's Overhead Transmission Lines Program between 1979 and 1987 and as an engineer at FP&L for over 20 years before that. He received a BS degree in electrical engineering from the University of Tennessee. ■

Beyond the Politics of Blame (page 14) is based on a speech delivered by **Jan Beyea** at EPRI's recent international symposium on global electrification. As chief scientist and vice president of the National Audubon Society, Beyea is primarily involved in the conservation and restoration of ecosystems, with particular emphasis on wildlife and biological diversity. Before joining Audubon in 1980, he spent four years doing energy research at Princeton University's Center for Energy and Environmental Studies. Before that, he served on the faculty of Holy Cross College, where he taught environmental studies and earth science. Beyea holds a BA from Amherst College and a PhD in physics from Columbia University. ■

COHPing With Particulates (page 18) was written by Leslie Lamarre, *Journal* senior feature writer, with guidance from **Ramsay Chang**, manager of particulate control in EPRI's Environment Division. Before coming to EPRI in 1987, Chang was with Acurex Corporation for eight years, serving as section leader and program manager in the Energy and Environmental Division. He holds three degrees in chemical engineering—a BS from Lehigh University and MS and PhD degrees from Stanford University. ■

Utilities Use Low-Cost Instrument to Gauge Solar Resources

About 25 member utilities have joined an EPRI- and national-laboratory-supported project to obtain more accurate assessments of the solar resources in utility service areas. Each of the participants is installing a new type of instrument that measures or calculates three key parameters that previously required separate devices. The new, low-cost instruments, based on rotating shadow-band pyranometers (RSPs), record diffuse radiation and total horizontal radiation and calculate direct-beam radiation. These data can then be used to calculate realistic energy production values for various types of photovoltaic (PV) systems in a utility's service area.

The new RSP instruments—available from two suppliers for under $10,000 each—make possible the low-cost acquisition of insolation data that previously required a significant investment to obtain. In an earlier effort with EPRI, the National Renewable Energy Laboratory (NREL) confirmed, in side-by-side tests at its calibrated Solar Radiation Research Laboratory, that the RSPs to be used in the project are accurate and reliable for utility needs.

Each utility is installing at least one RSP-based instrument to collect site-specific insolation data for at least one year. EPRI is providing a coordination contractor to work with NREL and Sandia National Laboratories personnel to provide technical support for the participating utilities, who by their involvement will gain a high-quality, site-specific solar database they can use to estimate PV system performance. The insolation data collected by the utilities may also be incorporated into NREL's National Solar Database.

A workshop held in Denver in May for participating utilities covered insolation measurement principles, instrument systems, data quality control, and PV system evaluation. Although the workshop was the official kickoff for the project, the participant roster is still open.

■ *For more information, contact John Bigger, (415) 855-2178.*

ASD Slashes Energy Consumption for Plastic Injection Molding

Nearly three-quarters of the more than 89,000 plastic-injection-molding machines used in this country operate by fluid power from hydraulic pumps that are driven by electric motors. Older molding machines have fixed-delivery hydraulic systems that are not very well matched to the molding operation's variable power requirement—and unused fluid power represents wasted energy. (Newer-generation machines have variable-delivery hydraulic systems that use 20% to 60% less energy.) The marketing department at Commonwealth Edison Company saw a major opportunity to retrofit an adjustable-speed drive (ASD) to an older injection-molding machine and document the energy savings over a range of operating conditions.

With support from EPRI's Center for Materials Fabrication in Columbus, Ohio, the Chicago utility launched a demonstration project to test and evaluate an ASD on an operating injection-molding machine used by one of its customers, Wise Hamlin Plastics. The ASD was installed on a 75-hp motor and configured with the appropriate interface to the machine's existing process control system. Observations over a range of operating conditions involving resin type, shot size, and cycle time indicated average energy savings of 41% when the ASD was in use.

Until now, operators of injection-molding machines have had almost no reliable data on ASD applications in the plastics industry with which to evaluate the technology. On the basis of the Commonwealth Edison demonstration, customer energy savings for the average injection-molding machine (in terms of size) are estimated at about 39,000 kWh a year. The large number of these machines makes this application of ASD technology a prime candidate for demand-side management programs in many utility service territories.

"The successful demonstration of ASDs for injection-molding hydraulic pumps will encourage others in our service territory to adopt this technology, reducing energy costs and demand requirements," says Commonwealth Edison's Todd Thornburg. EPRI estimates that the adoption of ASDs on just 10% of the country's injection-molding machines could result in total customer savings of 347 million kWh, worth about $20 million a year.

Details on these findings are presented in *Improving Energy Efficiency of Injection-Molding Machines* (EPRI CMF report 92-6), available from the Center for Materials Fabrication, (614) 424-7742.

■ *For more information, contact Gene Eckhart at EPRI's Washington, D.C., office, (202) 293-7517.*

Mobile Concrete Block Plant Demonstrates Use for Fly Ash

Eight utilities that operate coal-fired generating plants are hosting visits this year and next by a truck-mounted, EPRI-sponsored demonstration unit that is using some of each plant's by-product fly ash to make lightweight concrete blocks. Researchers believe that the blocks—produced through a new autoclaved cellular concrete (ACC) process—have great promise as a non-forest-product building material. Successful demonstration of the ACC process using a variety of utility ash materials, together with acceptance of the finished product by local building contractors and authorities, could open the doors for a ready-made alternative to landfill disposal. Utilities now spend about $1 billion each year for the landfill disposal of most of the 75 million tons of ash removed annually from the flue gas of coal-burning plants.

The demonstration concrete-manufacturing plant, contained on three flatbed trailers, has the capacity to turn out about 100 ACC blocks a day. At each utility plant, the unit will produce between 1000 and 2000 blocks as a means of acquainting members of the local construction community with the lightweight concrete's advantages and best applications. The unit first visited PSI Energy's Noblesville, Indiana, plant for a six-week operating run. It then headed for New England Power Company's Brayton Point plant in Somerset, Massachusetts, for a run of similar length. United Illuminating Company's New Haven station in Connecticut is hosting the unit in July and August. Later visits are scheduled for plants operated by Ohio Edison Company, Georgia Power Company, the Tennessee Valley Authority, Niagara Mohawk Power Corporation, and New York State Electric & Gas Corporation.

Produced and used for many years in some 40 countries, ACC (which contains no coarse aggregate) is made by mixing portland cement, lime, aluminum powder, and water with a large proportion of silica-rich material. The latter material is usually sand, although power plant fly ash has been used in England for over 25 years.

Virginia-based North American Cellular Concrete has pursued ACC product and market development for several years, much of it with EPRI support. With an eye to building and operating block-making plants at utilities, the company has designed a small plant for utility sites that can be expanded as the market for ACC grows. EPRI is pursuing commercialization efforts with the company and individual utilities on the basis of that design.

Thanks to several qualities—including weight that is one-fourth that of conventional concrete, resistance to fire and mildew, and a high thermal insulation value (R1.2 per inch)—market research has identified strong potential for the use of ACC blocks in such applications as foundations, interior partitions, and fire walls. In addition to blocks, ACC can be used to produce reinforced wall and roof panels.

The lumber- and energy-saving potential of this innovative building material is noted by Michael Miller, EPRI program manager for waste and water management. He says, "We're hoping its production can become part of an integrated system that provides a new alternative for disposing of the ash removed from coal plant flue gases and at the same time offers an energy-efficient, economical alternative to increasingly expensive wood products."

■ *For more information, contact Dean Golden, (415) 855-2516.*

Hotline Makes G&S Division Software More User-Friendly

Utility personnel who use any of the more than 40 PC-based software products of EPRI's Generation & Storage Division are now only a phone call away from support analysts who can help with problems and answer questions. The call (800-GSD-EPRI) is toll-free.

Using EPRI's RemoteLink PC-to-PC software, the staff at the Generation & Storage Software Support Center (GSSSC) can even provide a caller with on-line software installation and operation assistance via a two-way phone link to the caller's PC. The RemoteLink software enables the analyst to view the same information that is on the caller's computer screen and to provide interactive on-line support. Over 200 copies of RemoteLink have been distributed, and the service is available to all EPRI members requesting Generation & Storage Division software.

When the division created the GSSSC, located at EPRI's Electric Power Software Center in Dallas, Texas, it had multiple aims: improving customer support through problem solving and follow-up, tracking actual use of software, and providing feedback to research managers on the performance and value of software products. Periodic reports of caller activity and follow-up provide valuable market demand data to EPRI about its PC software. The pioneering effort could eventually be extended to cover all EPRI software.

Another innovation by the GSSSC involves upgrading the division's existing software programs to include an autoinstallation program. The autoinstaller feature makes loading an application onto a hard disk faster and easier. About 10 of the division's software releases have been upgraded so far, with as many as half a dozen a year to follow.

■ *For more information, contact Greg Lamb, (415) 855-2449.*

Assistance With End-Use Data

Looking for accurate load shapes for commercial air conditioning or ground-source heat pumps? Need help benchmarking engineering estimates with metered data? EPRI members answering yes to these and similar questions about end-use data can call the Institute's Center for Electric End-Use Data (CEED). The center has been handling queries from all over the country since its toll-free InfoLine was launched about a year ago. By dialing 800-DRS-0220, members can talk with experts who have end-use data and documentation at their fingertips.

The CEED InfoLine can also direct callers to the center's Data Request Service, a fee-based service in which analysts conduct customized searches of on-line databases of end-use load shapes, consumption data, and other information provided to CEED from actual utility metering projects. The center currently maintains residential data covering dozens of end uses from over 500 sites in the Midwest, Northwest, and Southwest; it has commercial end-use data from almost 100 buildings in the West.

Since its inception in 1991, CEED has been helping to satisfy the increasing requirements within the utility industry for accurate end-use data. The center publishes a quarterly newsletter, maintains a directory of end-use monitoring projects, sponsors conferences and workshops, develops research, and serves as a central agency for addressing end-use data issues.

Load researchers, rate designers, demand forecasters, customer service representatives, and utility demand-side management staff have been among the center's most active users. According to Terry Mayer of Idaho Power Company, "CEED is a really great idea whose time has come."

■ *For more information, call the CEED InfoLine at 800-DRS-0220.*

PowerServe Information Service in Pilot Release

As pioneer users of a new technology network called PowerServe, a small number of utilities are getting expanded, on-line access to the advanced technology services being developed at EPRI's regional centers around the country. A widearea information service under development by the Generation &

Storage Division, PowerServe is designed to complement the latest version of EPRI-NET as part of a coordinated electronic information system that can deliver details about the full spectrum of EPRI products and services to the desktops of individual utility users.

PowerServe links EPRI technology centers and provides specialized databases and services to help meet the needs of fossil plant personnel. Designed as a Windows 3.1 application for IBM 386DX or compatible PCs, it is intended to help utility personnel better understand and more quickly apply EPRI products.

The full release of PowerServe to EPRI members, expected in January 1994, will feature a number of new on-line electronic services, including computer-network-based interactive training, remote consulting with EPRI experts, on-line updating of EPRI software, a fax mail service, and direct access to software programs and resources from EPRI technology centers nationwide.

A handful of PowerServe applications from three regional centers have been developed for the pilot stage. They include an interactive, on-line guide to the services of the Monitoring & Diagnostic Center; MachineryLink, a database on rotating machinery and predictive maintenance; a guided introduction to the Combustion Turbine Center; a new release of the Advisor on Blade Coatings (an EPRI software package); and an electronic version of EPRI's directory of adjustable-speed drives.

Users at member utilities and service companies will have the capability to publish relevant information through PowerServe, which is expected to become a major source of information for the utility industry. The system is designed to accommodate the incorporation of applications regardless of whether they were designed specifically for PowerServe. Sargent & Lundy, the system developer, is available to adapt applications for delivery through the network. Or, by using a developer's toolkit, other contractors can develop or adapt applications for PowerServe.

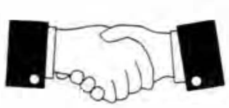
Boston Edison Company and Florida Power Corporation are the first in a small group of beta users that will be testing the new EPRI information service this year.

■ *For more information, contact Greg Lamb, (415) 855-2449, or Roy Fray, (415) 855-2441.*

Workshop on Technology Transfer in Business Planning

An evolving two-step process that uses information developed by EPRI can result in better technology transfer. About 170 attendees at the 1993 EPRI Technology Transfer Workshop, many of whom are managers of EPRI technology transfer (METTs) at their utilities, were briefed on the latest efforts to help utilities define and establish more-effective technology transfer programs to take competitive advantage of EPRI results. The two-and-a-half-day June workshop was held in San Francisco.

James Oggerino, manager for market penetration in the Integrated Energy Systems Division, presented highlights of a forthcoming EPRI workbook that utility staff can use in the first step of the two-step process: analyzing their own company to identify barriers to technology transfer. The workbook, *Technology Transfer and Innovation in the Utility Organization* (TR-102445), is based on the results of an EPRI project in which researchers conducted extensive interviews of 100 executives and 900 staff at nine member utilities. Utilities can apply the analytical process described in the workbook to uncover embedded cultural, institutional, and organizational impediments to technology transfer and innovation. Seventy generic impediments are listed, as well as tactical and strategic suggestions on how to overcome them.



The second step is for a utility to gain a better understanding of how to integrate EPRI technology into its strategic business planning. Howard Mueller, manager of member strategic planning in EPRI's Membership Division, described a joint planning initiative now under way. In it, EPRI member relations executives and planners work with utility executives and senior management to develop a strategy for leveraging EPRI technology and research capabilities in meeting an individual company's strategic business objectives. The goal is to strengthen the partnership between EPRI and its members by aligning EPRI's R&D products and programs with a member's highest-value business opportunities and needs. The result is a joint action plan for the utility and EPRI for integrating new EPRI technology.

Panel discussions at the workshop highlighted the team relationship being fostered between utility METTs and the technology transfer managers of EPRI's R&D divisions, the increasingly regional character of EPRI's efforts in technology transfer (through its assistance and application centers), and case studies of technology applications. Smaller-group sessions explored specific challenges of technology transfer, including strategic alliances and communicating value to management.

Robert Aldrich, EPRI vice president for integrated energy systems, told workshop attendees: "The responsibility is ours at EPRI more than ever to ensure that our members realize and take advantage of the value of our research results."

■ *For more information, contact Howard Mueller, (415) 855-2745, or James Oggerino, (415) 855-2663.*

Exploratory Research

Application of Chaos Theory to Corrosion Control

by John Stringer, Office of Exploratory & Applied Research

Chaos theory describes an underlying order in seemingly random phenomena, providing new approaches for understanding certain types of complex, nonlinear behavior that can arise in even the simplest of dynamic systems. Until recently most research investigating deterministic chaos has been theoretical in nature, but scientists and engineers are now beginning to examine practical applications for this rapidly developing science.

EPRI's Office of Exploratory & Applied Research is sponsoring several studies that are applying chaos theory in order to better understand utility systems exhibiting nonlinear dynamics (see *EPRI Journal*, June 1992, p. 4). In an investigation of nonlinearities associated with processes that influence the corrosion of power plant equipment, researchers at Battelle Memorial Institute (Columbus Division) and Ohio University are focusing on the kinetics of metal passivation (RP2426-25).

Passivation involves a reduction in the chemical reactivity of a metal surface under certain environmental conditions; unpassivated (active) surfaces are subject to corrosion processes that can lead to equipment failure. Passivation can be achieved by attaching sacrificial electrodes or power sources to a surface, thus changing the surface's electric potential relative to its environment.

As a surface is transformed from an actively corroding state to a passivated one, the surface-current density (that is, the density of the current passing from the metal surface into the surrounding solution) abruptly decreases. Until recently this rapid transition was poorly understood, limiting utility application of methods for encouraging passivation. EPRI-funded scientists have developed a theoretical model indicating that precursors of chaos underlie this transition and that chaotic behavior may occur while surfaces are actively corroding. The latter finding has been experimentally verified in an electrochemical cell. Concepts of nonlinear dynamics, including chaos theory, are currently being applied to devise novel methods for both controlling chaos and encouraging passivation in the model and the electrochemical cell. In future work, researchers hope to demonstrate these advanced corrosion control methods on utility equipment.

ABSTRACT *Chaos theory offers new approaches for understanding systems that exhibit certain types of complex behavior. Exploratory research is being conducted in a variety of utility-related fields to move the study of deterministic chaos from the realm of theoretical science to that of practical engineering. In one study, chaos theory is being applied to increase our understanding of materials processes and to develop novel approaches for corrosion control. Although near-term applications are unlikely, control algorithms developed during ongoing research could one day be used for avoiding or encouraging chaos in a variety of processes of interest to the utility industry.*

A chaotic transition

To determine whether chaos underlies metal passivation, EPRI researchers adapted sets of nonlinear equations from previous, two-dimensional, models to devise a simple corrosion model that simulates passivation kinetics. Nonlinearities can be either chaotic (globally organized but locally unpredictable) or stochastic (purely random) in nature. Since the identification of deterministic chaos requires models characterized by three or more independent state variables, the new model is three-dimensional.

In this model, nonlinear differential equations represent the kinetics of a system in which a metal surface is assumed to be dissolving in solution under an applied voltage and in which any given point on the metal surface is assumed to be either bare (active), covered by a soluble salt layer (active), or covered by an insoluble oxide coating (passivated). The oxide prevents direct dissolution of the base metal.

System behavior over time has been simulated, and changes in relative surface coverage and other variables have been plotted against each other. Figure 1 illustrates a strange attractor—a behavioral pattern characteristic of deterministic chaos—describing the relationship between surface coverage of the soluble layer and that of the insoluble, passivating layer. This plot has an underlying order, even though the relative distribution of each layer at any specific time is impossible to predict. By contrast, the plot would be a random scribble if the system were stochastic in nature.

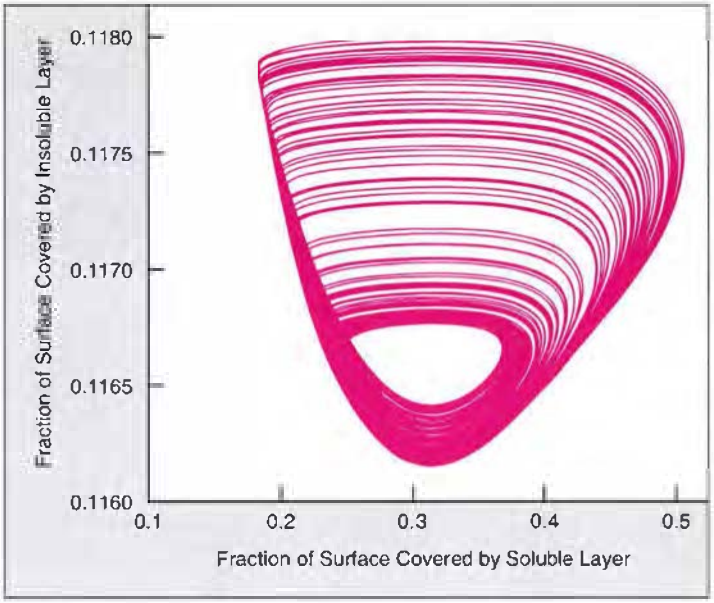
The discovery that chaos theory can be used to describe the formation of passivating layers provides a new perspective on corrosion and passivation. According to theory, the onset of deterministic chaos is preceded by bifurcations—points at which, as one or more parameters are varied, system behavior suddenly begins to oscillate between two sets of conditions, one or both of which may lead to instability. Thus the rapid transition in surface-current density that has been observed could represent a bifurcation between an unstable, corroding condition and a stable, passivated one.

To verify in a laboratory setting that chaotic dynamics can occur during metal passivation, EPRI researchers have designed an electrochemical cell to study the anodic dissolution of a copper rotating-disk electrode. As in the mathematical model, a soluble salt layer and a passivating oxide layer form when an anodic voltage is applied to the electrode. The soluble layer is copper (II) acetate, and the passivating layer is copper (I) oxide.

Experimental results indicate that under an applied potential the electrode surface current initially levels off to a steady value and then steadily decreases as the soluble acetate layer begins to form. When the surface is almost fully covered, the current drops precipitously, reaching a minimum when a complete coating is formed. As this soluble layer dissolves, the current slowly increases and then begins to oscillate. These oscillations may be associated with the competing acetate/oxide film formation and dissolution processes.

Both periodic oscillations and very complex, aperiodic oscillations in current have been observed, depending on the applied potential and the electrode's rotation rate.

Figure 1 Strange attractors represent the behavioral "signature" of deterministic chaos; they can appear when key variables of a nonlinear system are plotted against each other. This attractor, which provides evidence of chaotic dynamics associated with a mathematical model of passivation kinetics, resulted when variations in the relative surface coverage of soluble salt and insoluble (passivating) oxide layers were plotted.



As shown in Figure 2, small changes in rotation rate can shift the surface current from stable to chaotic behavior.

Control of deterministic chaos

Given the finding that minor changes in anodic potential can be used to adjust surface-current dynamics, ongoing research is focused on the development of methods for controlling this chaotic system.

Such methods are possible because both periodic and chaotic orbits (operating regions) exist within strange attractors. The periodic orbits are unstable, causing the surface current to oscillate from orbit to orbit. To achieve stability, the current can be "balanced" on a periodic orbit by very small, purposeful adjustments of anodic potential.

Scientists are testing a surface-current control strategy based on a recursive proportional feedback algorithm that is activated when the surface current approaches a periodic orbit. Anodic potential is adjusted by using a feedback term proportional to the distance from the desired orbit, as well as a recursive term proportional to the previously implemented control step. This novel

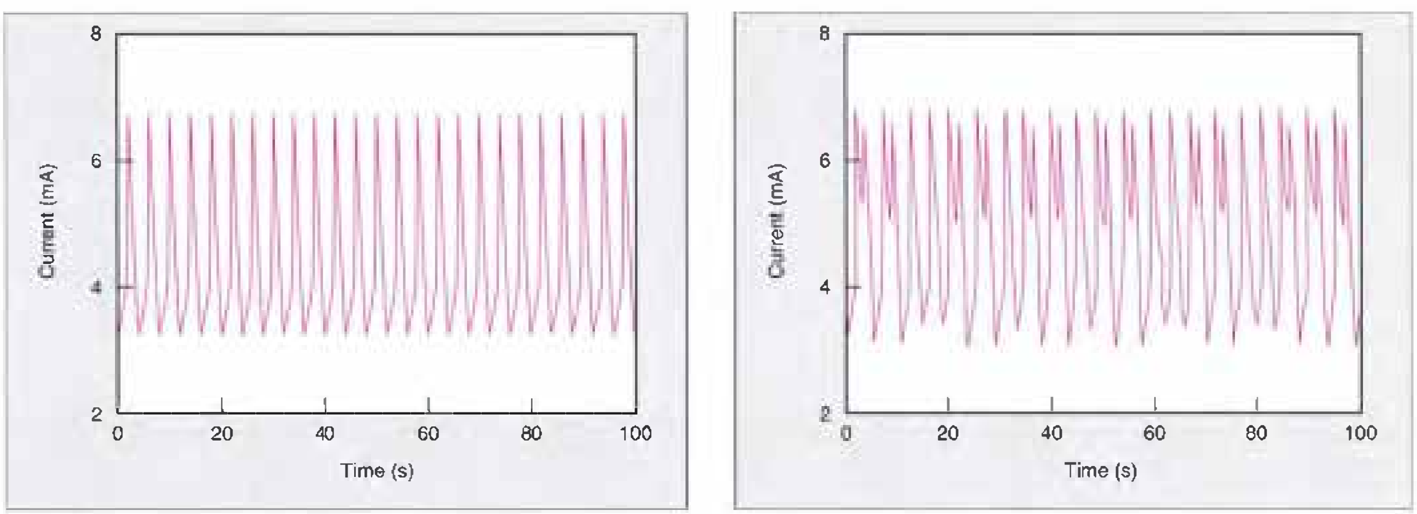
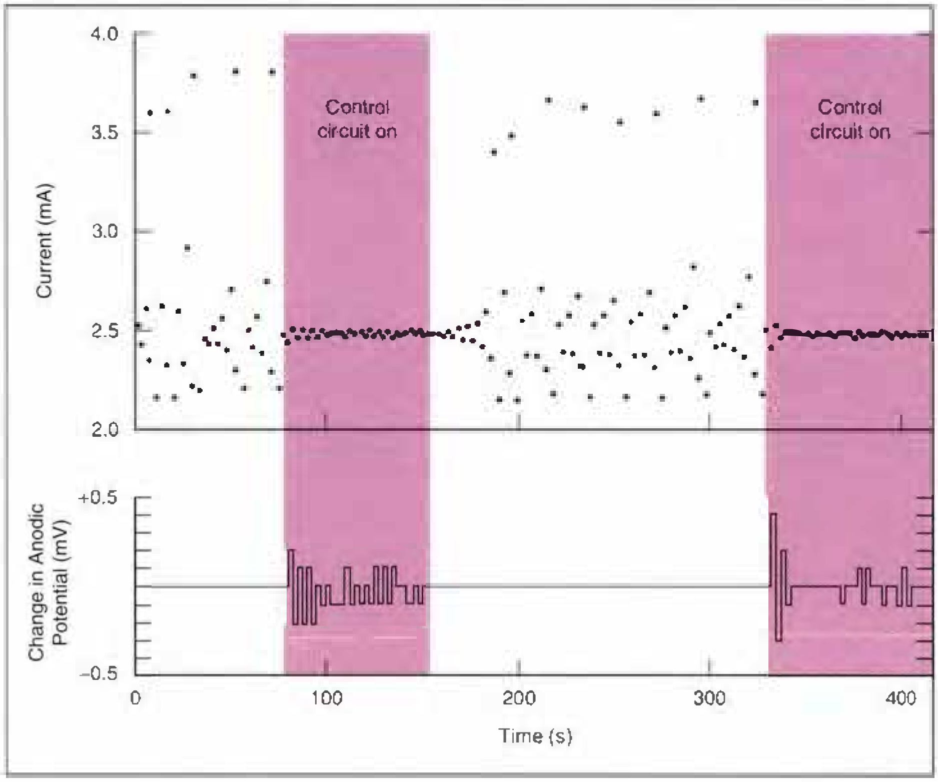


Figure 2 The behavior of systems exhibiting deterministic chaos varies widely, depending on initial conditions and parameter values. These results, for example, show how a small change in electrode rotation rate in an experimental electrochemical cell can shift surface-current behavior from stable to chaotic oscillations. The rotation rate was 2400 rpm in the graph on the left and 2533 in that on the right; in both cases, the anodic voltage was 0.770 V.

Figure 3 One of the potentially most important applications of deterministic chaos theory is the control of nonlinear systems. Researchers have developed a powerful control algorithm and applied it to an experimental electrochemical cell, using it to shift the surface current back and forth between periodic and chaotic oscillations, as shown here. This novel algorithm could make it possible to sustain, within a chaotic attractor, types of dynamic behavior never before achievable.



algorithm has been applied to both the mathematical model and the electrochemical cell. As shown in Figure 3, which illustrates experimental control of chaos in the electrochemical cell, small perturbations introduced in the anodic potential hold the surface current on a periodic, more regular oscillation; when the control circuit is turned off, chaotic oscillations resume. To the researchers' knowledge, this is the first reported instance of chaos control in an actual electrochemical system.

In addition to being considerably more powerful than existing techniques, the new algorithm is generic, opening up new possibilities for controlling the effects of nonlinearities in other utility applications. It could make it possible to sustain, within a chaotic attractor, types of dynamic behavior never before achievable. For example, for a battery with a chaotic operating regime, one orbit might provide high power output at low efficiency, whereas another might offer a lower power output at a higher efficiency. Battery operation could be optimized by means of a control scheme that switches between orbits at certain intervals or in response to operating requirements.

Chaotic behavior could be eliminated in some applications — such as power systems, where it could lead to instabilities and perhaps voltage collapse. Or it could be promoted in other cases — in fluidized-bed combustors, for example, to optimize the turbulent mixing of fuel and air that leads to higher combustion efficiency. A third possibility would be to balance a system on an unstable fixed point, so that neither periodic nor chaotic behavior would be observed. A future goal for this project is to achieve control on a fixed point characterized by zero current, where a metal surface is completely passivated and corrosion is eliminated.

Land and Water Quality

Restoration of an MGP Waste Disposal Site

by Ishwar Murarka and Adda Quinn, Environment Division

In 1987 EPRI initiated a research project called EBOS (environmental behavior of organic substances) to examine the fate of organic wastes at former manufactured gas plant (MGP) disposal sites. Such research is important because constituents of these wastes — for example, the polycyclic aromatic hydrocarbons (PAHs) released by coal tar — could pose a threat to human health and the environment if they enter underground water supplies.

EBOS initially focused on the natural processes that promote the release, transformation, and movement of coal tar constituents in the environment. Understanding these processes is essential for assessing the nature and likelihood of groundwater contamination, choosing the best means of remediation for a given site, and evaluating the success of remediation efforts. Recent EBOS research has focused on predicting how well chosen remediation efforts will work.

EBOS field studies began in 1987 at a coal tar disposal site in New York, known as Site 24. EPRI started its work there with the support and cooperation of the site's owner, Niagara Mohawk Power Corporation. The three major goals of the research at Site 24 were to find efficient, cost-effective methods of sampling and analyzing soils and groundwater, to investigate the fate of tarry materials in the environment, and to assess the efficacy of restoration actions undertaken.

In the case of Site 24, the owner elected to remediate the site by removing the source of contamination. Subsequent monitoring at the site has shown significant decreases in contaminant concentrations in a downgradient aquifer as a result of that remediation.

ABSTRACT *Former manufactured gas plant (MGP) disposal sites pose a challenge to investigation and effective remediation because their tarry wastes release organic constituents that transform, migrate, and persist in the environment. EPRI researchers have studied the hydrological, chemical, and biological processes at work at an MGP disposal site—both before and after the utility owner removed the buried coal tar and tar-contaminated soils. A 10-year-long monitoring program is under way at the site, and initial results indicate that source removal is an effective means of site restoration. Data from the long-term monitoring will be used in refining the MYGRT and ROAM computer codes, designed to help utilities evaluate MGP site remediation options.*

Finding the source of contamination

EPRI's research at Site 24 started 25–30 years after MGP workers had put 4000–16,000 gallons of coal tar in a large trench beside a country road and covered the tar with sand. No records documented the exact volume of tar or the precise disposal location, and the site was forgotten until a utility worker detected coal-tar-derived organic compounds several hundred feet downgradient from the buried waste.

Site 24 was an ideal location for research on the environmental processes that control the release, migration, and persistence of organic compounds from MGP tars. It was a rural field with no structures to influence the natural movement of groundwater; it had only one tar source (the waste buried in the trench); its underground aquifer was composed of silty sands above a confining layer of clay located about 22 feet below the surface; and its sandy soils had little organic carbon that could adsorb tarry residues.

To find the tarry source, researchers placed a grid over the entire site and determined soil and groundwater sampling locations—including locations for piezometers, multilevel samplers, and monitoring wells. Rapid borings revealed approximately 8000 cubic yards of source material (tar and tar-contaminated soils), primarily north of the road. Most of the highly contaminated material was located at or below the water table at depths from 7 to 22 feet.

Defining the contaminant plume

Data from piezometers and groundwater wells installed at various locations across the site showed that the groundwater flowed from the source, under the road, to a downgradient seep about 1200 feet away. Trickles from the seep formed a small stream that eventually reached the Hudson River. Samples showed that the PAH naphthalene was present in the seep sediments, but no PAHs were detected in the stream water entering the river.

Researchers used a multistep method to place groundwater wells at optimal locations and depths for sampling the contaminant plume. First, they defined a series of transects that cut across the site approximately perpendicularly to the direction of the groundwater flow. Then they made several borings along each transect, starting from the edges and working toward what appeared to be the centerline of the plume. Each boring yielded soil samples from various depths, which the researchers then subjected to extraction and analysis in a rapid-turnaround field laboratory. (See the September 1990 *EPRI Journal*, p. 40, for a full description of the innovative analytical techniques used.) In analyzing the samples, the researchers focused on naphthalene because it was the most abundant and mobile of the coal-tar-derived PAHs from the source tar at Site 24. Field laboratory results were used in determining the location of new sample borings.

Finally, along each transect, the researchers chose the boring with the highest concentration of naphthalene as the location for a groundwater well. After studying the vertical distribution of naphthalene concentrations in each such boring, they placed a short (approximately 2-foot) collection screen at the depth with the highest naphthalene concentration. They also placed fringe wells at the edges of the plume to delineate its outer boundaries. This method of well placement proved to be a reliable technique for ensuring optimal monitoring.

The results of the field investigation at EBOS Site 24 showed that a fairly narrow plume of tar constituents moved with the groundwater away from the source area. It was apparent that at this site the coal tar released its constituents to the environment primarily by dissolution. Thus the inclination of a particular constituent to dissolve in water—along with its potential for attenuation and degradation—dictated how much of it would move with the groundwater. Naphthalene, being the most soluble PAH—with a maximum predicted solubility (mps) of 14 mg/L—moved the farthest; acenaphthylene (mps, 0.5 mg/L) and phenanthrene (mps, 0.4 mg/L) moved a shorter distance; and benzo(a)pyrene (mps, 0.001 mg/L) did not show any significant movement away from the source area.

Once dissolved, the PAHs flowed with the groundwater by advection and dispersed very little in either the vertical or transverse direction. Although the contaminant plume came close to the water table near the source, it dropped gradually as it moved downgradient and occupied a narrow vertical span in the sandy soils between the water table and the confining layer of clay.

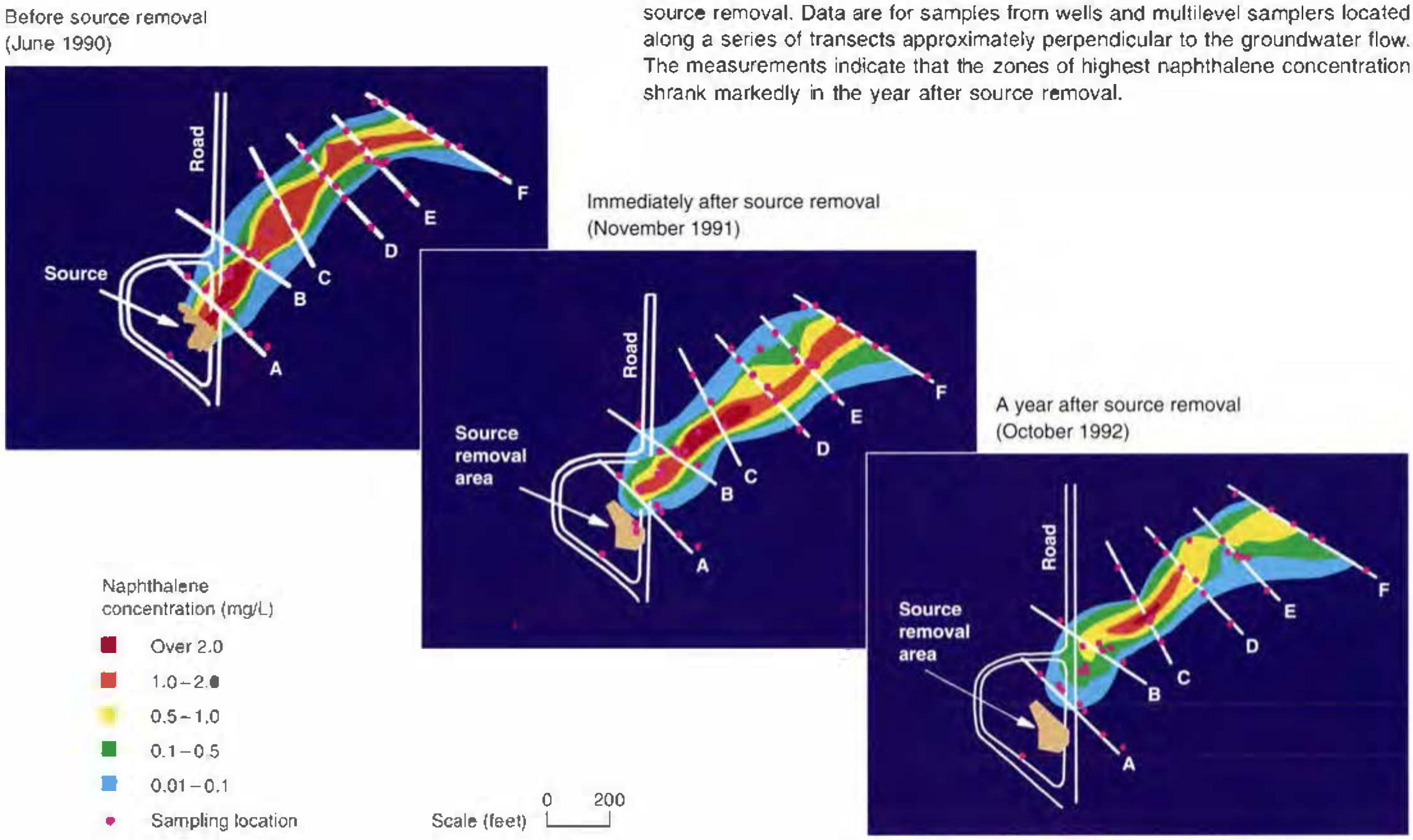


Figure 1 Groundwater naphthalene plume at EBOS Site 24 before and after source removal. Data are for samples from wells and multilevel samplers located along a series of transects approximately perpendicular to the groundwater flow. The measurements indicate that the zones of highest naphthalene concentration shrank markedly in the year after source removal.

Removing the source

In 1991 Niagara Mohawk contracted with Atlantic Environmental Services to remove all of the source tar, tarry soils, and wastewater and to restore the source area. Work began in May, as the contractor prepared the site by diverting traffic, closing the road, and erecting a perimeter fence with a locked gate. Near the excavation area, workers placed plastic liners to hold contaminated soils awaiting transportation off-site, and they constructed a plastic-lined wastewater pond to hold the water pumped out during excavation. Finally, they drove sheet piles about 30 feet deep, well below the known clay layer, to form a cofferdam completely surrounding the area where the tar and tarry soils were located.

During the actual excavation, workers used backhoes to remove approximately 9400 cubic yards (15,000 tons) of tarry soils, tar-contaminated soils, and some adjacent clean soils. In testing, none of these soils exhibited characteristics defined as hazardous by the Environmental Protection Agency (including toxicity, ignitability, reactivity, and corrosivity). Therefore they were suitable, without further treatment, for use as raw materials in the manufacture of asphalt and portland cement.

Two facilities did trial studies using the contaminated soils to produce portland cement, and a third facility used the soils to produce hot-batch asphalt. All three facilities employed thermal desorption techniques with rotary kiln technologies, performed the trial burns satisfactorily, passed audits by the contractor, and had secure storage for the contaminated soils. The asphalt plant proved to be superior on the basis of total cost, and it subsequently treated most of the soils (about 11,500 tons) for about $106 per ton. One of the portland cement plants processed roughly 3600 tons of contaminated soils for about $172 per ton. Processing at the other portland cement plant would have cost $210 per ton.

Tests of the wastewater pumped out during excavation showed that it required no pretreatment, and the local water treatment plant accepted 737,000 gallons for disposal.

By mid-October the contractor had removed all tar, contaminated soils and water, and plastic liners from the site and had filled the excavated hole with clean native sand and soil. Workers removed and decontaminated the sheet piles and transported them off-site. They replaced the EPRI research wells and piezometers that had been destroyed during the excavation process. Finally, after leveling the disturbed area, they fertilized and seeded it.

Measuring the shrinking plume

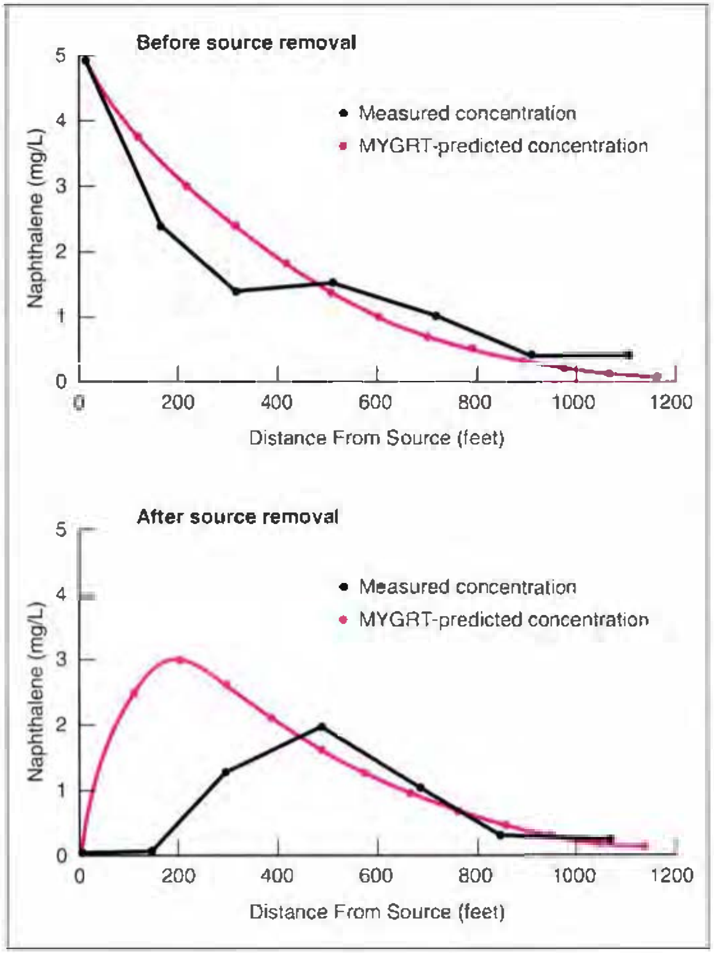
Using naphthalene concentration as their indicator, researchers have been monitoring the groundwater contaminant plume at EBOS Site 24 since source removal. A comparison of pre- and postremoval naphthalene concentrations indicates that the plume is rapidly shrinking.

Figure 1 presents plots of naphthalene concentration before source removal, immediately after source removal, and one year after removal. They reveal a marked reduction in the concentration of naphthalene in the plume and show that the zone of highest concentration has moved from near the source area to the Transect C area. Very little naphthalene remains near the source area.

Depth analyses of the plume corroborate these findings. Multilevel sampling in June 1990 at Transect C — approximately 400 feet downgradient from the source — showed the naphthalene plume spanning about 5 vertical feet in a layer of fine sand just above the confining clay. Naphthalene concentrations in this fine-sand layer decreased dramatically after source removal. Multilevel samples taken between Transects A and B showed that the maximum naphthalene concentration of about 3 mg/L in June 1990 dropped to about 0.7 mg/L in November 1991 and to less than 0.3 mg/L in October 1992. Naphthalene concentrations measured in multilevel samples taken at or near the plume centerline indicate that the vertical thickness of the plume is also shrinking, with the most dramatic changes occurring in the area near the source.

Taken together, these measurements show that source removal can be a highly effective remediation strategy for MGP sites.

Figure 2 Measured and predicted naphthalene concentrations along the groundwater plume centerline at Site 24. The top graph shows average concentrations measured before source removal; the bottom graph, concentrations measured in October 1992, about one year after source removal. Predictions by EPRI's MYGRT code were generally in agreement with the measurements. The exception—the fact that the plume is dissipating near the source area more quickly than predicted — may be partly the result of subsurface microbial activity.



Predicting plume change

Before source removal, researchers sampled the groundwater at Site 24 twice — in September 1989 and again in June 1990. Figure 2 shows not only the average concentrations of naphthalene found at the plume centerline but also the concentrations predicted by the EPRI code MYGRT™ 2.0, a user-friendly personal computer code designed to evaluate and predict the migration of organic and inorganic chemicals in groundwater. As the figure shows, the MYGRT predictions of naphthalene concentrations at EBOS Site 24 before source removal were very close to the measured concentrations.

As noted earlier, researchers also collected groundwater samples twice after source removal — in November 1991 (immediately after removal) and in October 1992. Figure 2 also shows the measured and MYGRT-predicted naphthalene concentrations for the 1992 samples. Near the source area, the naphthalene plume appears to be dissipating much faster than anticipated, although in the area between Transects C and F (400 to 1100 feet downgradient from the source), it is changing as predicted by MYGRT.

The fact that the plume is dissipating more quickly than predicted — especially near the source area — suggests a need for the long-term research EPRI is now conducting at Site 24 to understand the physical, chemical, and biological changes introduced by source removal.

One biological process that may be important in the rapid dissipation of the naphthalene plume at this site is subsurface microbial transformation. Researchers from Cornell University showed that there were indigenous PAH-degrading microorganisms in the groundwater plume at Site 24. Recent dissolved-oxygen results support the suggestion that these microorganisms may be mineralizing naphthalene. The samples taken in October 1992 indicate that groundwater dissolved-oxygen concentrations decrease significantly from the plume edges to the centerline — the pattern of dissolved-oxygen distribution one would expect if microbes were metabolizing most actively where PAHs are most concentrated. These results support the hypothesis that there is microbial activity in the groundwater plume, and they complement observations of such activity in Site 24 soils (*EPRI Journal*, March 1993, p. 34).

Choosing a remediation strategy

Removing the source of contamination at MGP sites is one of several remediation options. EPRI researchers are developing the Remediation Options Assessment Model (ROAM) to evaluate soil and groundwater conditions pre- and postremediation at MGP sites. ROAM will also help users assess various soil and groundwater remediations for an entire disposal site. Soil remediation measures include capping, excavation, and in situ bioremediation. Groundwater remediation measures include pumping and treatment, hydraulic barriers, and gravity drains. ROAM provides a multitude of options for site characterization and for analysis of various cleanup scenarios (including taking no action). Researchers are currently using data from EBOS Site 24 to test ROAM.

Maintenance of Solenoid-Operated Valves

by Vic Varma, Nuclear Power Division

Solenoid-operated valves (SOVs) are widely used in the nuclear power industry in the United States. Utilities estimate that there may be 1000–2500 SOVs in a typical LWR power plant. BWRs generally have more solenoid valves than PWRs.

Economical in initial cost and easy to operate, SOVs can be ac- or dc-powered and can be used to control fluid flow directly (in line applications) or indirectly (as pilot controllers). They are used in both safety- and non-safety-related systems. The two most common power plant applications of SOVs are as air-pilot valves for controlling air-operated valves and as main process valves in fluid systems. SOVs are also used in hydraulic systems and in power-operated relief valve (PORV) applications.

Because of some reported SOV failures, the Nuclear Regulatory Commission conducted a study of valve operating experience, which was published in 1991 (NUREG-1275, Volume 6). Simultaneously, the Nuclear Maintenance Applications Center (NMAC), operated by EPRI, organized an industry technical advisory group to prepare guidelines for SOV maintenance and application. As the basis for these guidelines, the group undertook an analysis of SOV failure and maintenance data from nuclear power plants. The resulting technical guide, published in 1992 as EPRI report NP-7414, is designed to help nuclear plant personnel understand, evaluate, and resolve any potential maintenance problem related to the operation of SOVs.

Valve operation

An SOV is actuated by energizing a solenoid coil with sufficient voltage. When the coil is energized, it produces a magnetic field to attract a plunger assembly. Depending on the mechanism, the plunger will open or close the valve attached to it. Such direct-acting SOVs can be economically manufactured only in small sizes and are designed for low-pressure applications.

For large SOVs or for high-pressure systems, the force developed by the solenoid coil is inadequate to operate the valve. In these applications, a piloted solenoid valve is required. Figure 1 is a simplified diagram of a piloted SOV. When the main disk and the pilot valve are closed, the system's inlet pressure provides the seating force for the main disk and tightly closes the valve (assuming that the outlet pressure is zero). When the pilot valve is opened, the main disk chamber rapidly depressurizes and the inlet pressure acting below the main disk unseats the valve. A small spring is often used to help with alignment, seat the disk properly, and provide operational stability. The force of this spring is generally not significant compared with the other forces acting on the main disk.

To operate reliably, most piloted SOVs require a minimum operating pressure differential (MOPD) between the main disk chamber and the outlet. If the MOPD falls below the specified minimum, the valve may not seat properly and may leak internally. Also, most piloted SOVs are unidirectional. If these valves are inadvertently reversed during installation, they will invariably leak.

When a piloted SOV is closed under normal conditions, the pressure in the main disk chamber will remain equal to the inlet pressure. Under certain transient conditions, however, the inlet pressure can rise significantly before the flow through the inlet orifice balances the main disk pressure. If the transient is rapid enough, the inlet pressure at the bottom of the disk can momentarily open the valve. This phenomenon is called burping. Burping does not occur if the valve design or application permits rapid equalization of the main disk chamber pressure with the inlet pressure. Nor does it occur if the process medium is an incompressible fluid and no air or gas is present in the disk chamber. Proper venting of air from the system and proper valve orientation to prevent air entrapment can reduce the possibility of burping.

Valve materials

SOVs can have hard or soft seats. Hard-seated valves have a metal-to-metal seat-

ABSTRACT *Solenoid-operated valves (SOVs), which are widely used in U.S. nuclear power plants, primarily in instrument air and process valve applications, are receiving increased regulatory and utility attention. EPRI's Nuclear Maintenance Applications Center organized an industry technical advisory group to analyze data on power plant experience with SOVs and to develop a guide on the maintenance and application of these valves. Utilities can use this guide in planning maintenance programs to improve SOV performance, in training plant maintenance personnel, and in selecting or specifying SOVs for various power plant applications.*

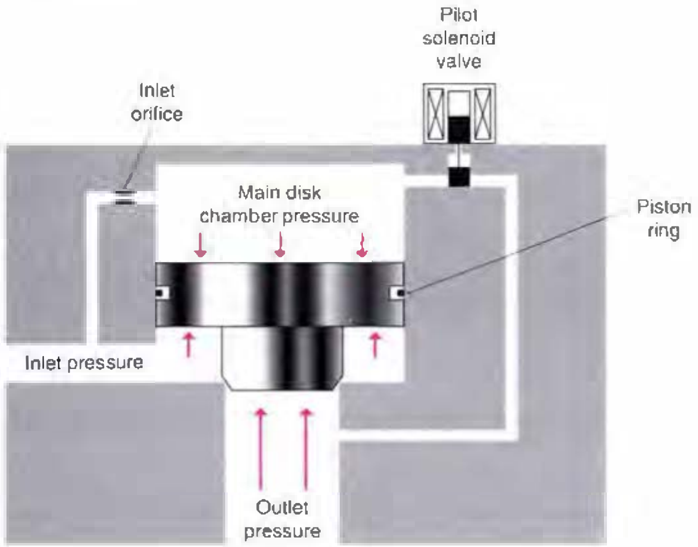
ing to close the valve port. Soft-seated valves have an elastomer or plastic material at the seating surface. Soft seats tend to be more effective than hard seats in blocking the leakage path. However, soft-seated valves can be used only at temperatures below approximately 350°F.

In hard-seated valves, leak blockage is achieved by highly finished mating surfaces. These surfaces can easily be damaged by contaminants trapped between them when the valve is closed. In high-pressure and high-temperature systems, once a seat is scored and leakage has developed, the "wire drawing" effect of the fluid flowing through the leakage path can quickly and severely damage the valve seat. It is possible to repair hard seats by lapping in the early stages of damage, but if the leakage goes unchecked, the replacement of disks and seats may become necessary.

Brass is the most common material for valve bodies in air-pilot SOVs and smaller process valves. Some larger valves may be made of bronze. Stainless steel is used for all other SOVs. Neither brass nor bronze is an acceptable material under Section III of the ASME Boiler and Pressure Vessel Codes. Since certain acids and corrosion products can attack brass and bronze, their use is not recommended in safety-related systems or with certain hydraulic fluids (e.g., Fyrquel).

A wide variety of plastics and elastomers are used in SOVs, either as molded parts or as gaskets and seals. Some of these materials can degrade severely with heat or contact with petroleum-based lubricants. A degraded elastomer seat in contact with a petroleum lubricant can form a sticky substance that prevents the valve from opening. Also, valves installed in radioactive environments must be evaluated for the long-term effects of radiation on the elastomer parts. Table 1 summarizes the properties of various plastics and elastomers.

Figure 1 Simplified diagram of a piloted solenoid-operated valve. In a piloted SOV, the solenoid is too weak to operate the main disk directly; instead it operates an internal pilot valve that controls the pressure in the disk chamber. Piloted SOVs are used in applications involving high flows and pressures.



Valve applications

The vast majority of power plant SOVs are used in pilot applications to control the operation of air-operated valves. Most of these air-pilot SOVs are brass bodied. Also, they typically use soft seats to minimize air leakage. The most common seat material is Buna-N; EPDM (a form of ethylene propylene) and Viton are used extensively in safety-related applications.

The second-most-common application of SOVs in power plants is as the main process valves in steam, water, gas, and other fluid systems. These valves range in size from the small valves used on 100-psig systems to 8-inch valves rated at 2500-psig and 5000-gpm flow. Virtually all process SOVs are two-way on-off valves. While a large percentage of the high-pressure steam valves are of piloted globe construction, the smaller valves used to control flow in low-pressure systems (e.g., cooling water, fuel transfer) are often soft-seated, piloted diaphragm or piston types.

Power-operated relief valves are a unique SOV application. PORVs are designed to provide short-term blowdown of high-pressure, high-temperature steam/water systems. They are used on pressurizers, main steam headers, and automatic BWR depressurization systems.

The valve flow coefficient is a critical factor in properly sizing a valve for its application. This coefficient is calculated for each valve on the basis of its flow capacity and the pressure drop within the valve. Designers tend to specify oversized valves rather than the exact size required for a particular application. That may not be a good practice in the case of piloted SOVs. Oversizing a piloted SOV may reduce its tolerance to reverse pressurization, increase the possibility of leakage (because of the larger seating area), and fail to provide the MOPD required to operate the SOV.

Failure analysis

Before the technical advisory group organized by NMAC could recommend maintenance actions, it was necessary to determine the various modes, mechanisms, and causes of SOV failure. One source of this information was the Nuclear Plant Reliability Data System (NPRDS), maintained by the Institute of Nuclear Power Operations. The NPRDS data were supplemented by maintenance data from various power plants. Detailed analysis of the collected data was necessary, since SOV maintenance is usu-

Table 1
PROPERTIES OF PLASTICS AND ELASTOMERS

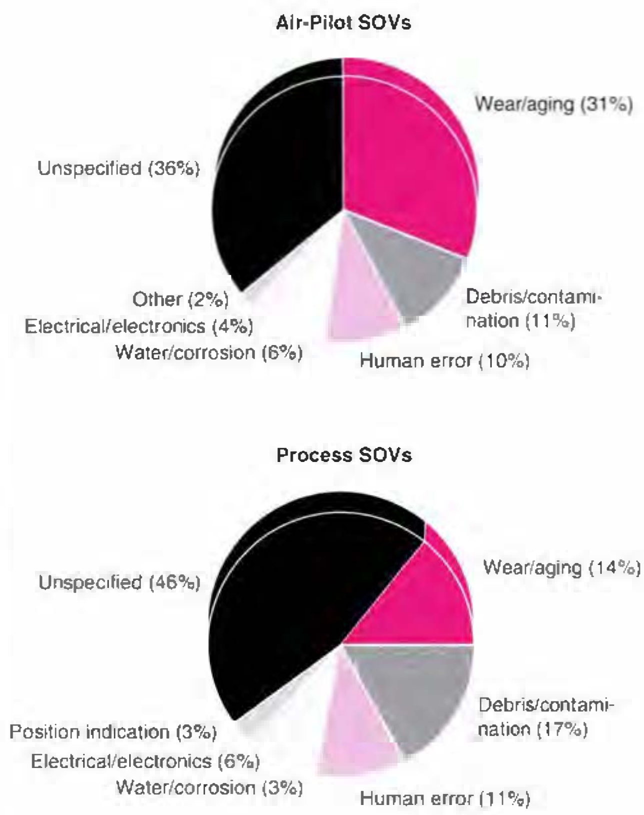
Material	Resistance to Petroleum	Temperature Limit (°F)	Radiation Limit (10^6 rads)
Buna-N	Good	180	100
Neoprene	Fair	200	100–200
Ethylene propylene (EPDM)	Poor	300	100–200
Viton	Excellent	400	10–20
Silicone	Good	450	50–200

ally recorded under the primary equipment. For example, an air-pilot SOV may not be identified individually but listed as part of the air-operated valve on which it is mounted.

Among the identified failure mechanisms (i.e., the processes resulting in failure) for air-pilot and process SOVs, the data analysis showed the major ones to be electrical coil failure, degradation of seating surfaces, and accumulation of debris and corrosion products. The dominant causes of failure were found to be wear and aging, contamination, and human error (Figure 2).

A large number of SOV failures occur because of moisture intrusion or prolonged operation at high temperatures or both. When a solenoid coil is energized, heat is generated. In dc coils the amount of heat generated is determined simply by the coil resistance and the operating voltage. In ac coils additional heat is generated by current circulating in the shading ring and by eddy-current losses. If an obstruction prevents a solenoid plunger from traveling to its furthest point, higher currents will continue to flow through the coil, generating even more heat. As a rule of thumb, coil material life is halved for every 10°C (18°F) increase in coil temperature. This rule of thumb also applies when a solenoid valve is heat traced or unintentionally insulated along with the piping.

Figure 2 An analysis of data from the Nuclear Plant Reliability Data System for 1985–1990 indicates the major identified causes of failure for air-pilot and process SOVs to be wear/aging, contamination, and human error.



Maintenance recommendations

The maintenance of solenoid valves does not always involve repair of the defective components. In fact, at least one major supplier of nuclear-grade SOVs discourages the repair of its valves in nuclear power plant safety systems. Furthermore, a large number of the solenoid valves used in balance-of-plant systems are small and inexpensive. Thus it is more cost-effective to replace them than to repair them.

It is highly recommended, however, that repaired or replaced valves be analyzed for cause of failure. The failure cause may be external to the valve itself (e.g., dirt or debris in the pipeline). If the root cause is not removed, the replacement valve is also likely to fail. In addition, periodic troubleshooting can reduce the risk of sudden operational failures. The list on page 45 presents some troubleshooting guidelines.

The use of incorrect replacement parts is reported to be a major maintenance problem. Some valves are available in both ac and dc versions, and these versions may have similar model numbers. An ac coil has a much lower resistance than a dc coil. If an ac coil is installed in a dc circuit, the valve may at first appear to operate perfectly, but the coil is likely to burn out in a short time. Conversely, if a dc coil is installed in an ac solenoid, the valve may not operate or may operate sluggishly because the magnetic force is inadequate. When ordering replacement parts, utility personnel should carefully review part numbers with the supplier. If the valve type is in question, the coil resistance should be measured to determine if the proper coil is being installed.

Solenoid valve failures due to defective coils are rare. However, coil failures may occur because of high ambient temperature or, as noted earlier, because of internal heat generated when the valves fail to open fully. The latter condition can be identified by an excessive hum when the coil is energized. Coil life generally ranges from 4 to 10 years when coils are operated at the rated temperature for the insulation class. It is also important to note that a continuously energized coil may become too hot for a standard cable termination (rated for 90°C, or 194°F).

Coil failures may also result from the intrusion of moisture into the coil housing. Non-safety-related valves are usually supplied with general-purpose coil enclosures that do not provide protection against moisture and dust. For most power plant applications, it is recommended that water- and dust-tight enclosures—that is, NEMA (National Electrical Manufacturers Association) Type 4 enclosures—be specified.

One of the best preventive maintenance techniques for SOVs is periodic on-off cycling. No single cycling frequency can be recommended for all the SOVs in a power plant. Rather, it is recommended that the cycling frequency be determined by plant personnel on the basis of operating experience. One rule of thumb is to cycle air system SOVs quarterly; longer intervals can be justified, however, when no prior operating problems have been experienced.

Since there are no proven techniques for monitoring SOV condition, it is recommended that in addition to corrective maintenance, age-sensitive parts be periodically replaced and selected SOVs be periodically rebuilt to maintain long-term valve operability. Two major components that are candidates for periodic replacement are coils and elastomeric components (e.g., seats, diaphragms, and seals). Most periodic replacements are specified in plant environmental qualification (EQ) programs under 10 CFR 50.49. For SOVs that are not controlled under EQ programs, periodic replacement intervals can be based on the manufacturers' recommendations or on operating experience.

In developing a maintenance program, the criticality of each SOV should be established. Valves typically fall into one of three categories: safety related, important to power production, and other. Valves in the last category may not warrant periodic maintenance; for them, replacement on failure may be the appropriate maintenance strategy. For safety-related valves, licensing or EQ documents define maintenance requirements, which should be considered minimum requirements. For other valves important to power production or to safety (but not subject to licensing or EQ requirements), credible failure modes should be evaluated in order to determine maintenance requirements. As an example, a normally closed, deenergized SOV's only safety function is to remain in that state. For such a valve, periodic maintenance may be unnecessary. For valves that are required to change states and maintain a minimum seat leakage, periodic maintenance is appropriate for performance and reliability.

In order to ensure that proper maintenance work has been performed, every repair or replacement should be followed by testing. This post-maintenance testing should be designed to demonstrate that the original problem has been corrected, that normal operation has been maintained, and that the equipment is capable of performing its design functions.

For further information about SOV maintenance, contact Vic Varma at (704) 547-6056.

SOV Troubleshooting Guidelines

- Visually inspect the valve for physical damage, loose electrical or piping connections, and leakage (including any obvious water, moisture, or chemical deposits).
- Verify that the actual direction of flow corresponds to the direction of flow marked on the valve.
- Check for the smell of burned coil insulation, which may indicate high coil temperature. (Infrared thermography can also be used to detect high-temperature operation.)
- If possible, remove the cover, and look for evidence of electrical arcing, insulation cracking, and other signs of age. Also, look for rust and water rings, which indicate moisture intrusion.
- Energize the coil, and listen for its characteristic click. The absence of this sound indicates that the travel of the solenoid plunger is restricted. Excessive hum or chatter is an indication of potential electrical and/or mechanical problems.

Fossil Plant Operations

Human Factors Guidelines for Control Rooms

by Roy Fray, Generation & Storage Division

The field of human factors, which focuses on the interactions between people and equipment, is sometimes overlooked or ignored in designing new equipment or operator interfaces. It is thought of as an unnecessary substitute for common sense and as a burden in terms of project schedules and costs. However, considering human factors early in a project can avoid costly errors and can result in a higher-quality product that is easier to use. This approach can reduce project costs, shorten schedules, and improve plant operation over the life of the product—benefits suggesting that human factors should be an important part of the design process.

EPRI's support for human factors technology began 15 years ago in the Nuclear Power Division. In 1984 EPRI published guidelines (CS-3745) for the application of human factors in fossil power plants. Recently, a revised version of those guidelines that features new sections on cathode-ray-tube-based control systems and CRT screens was issued (TR-101814).

The new guidelines were written in response to substantial improvements in control room equipment and in the capability of CRT displays. Modern control rooms use CRT-based digital control systems instead of hard control panels. This introduces a whole new set of human factors issues related to arranging the new equipment effectively for control room operators. Perhaps even more dramatic is the advancement in the capability of CRT graphics. The range of CRT display hardware and image-building software is astonishing. All of this capability may create confusion for display designers and increases the potential for both good and bad operator-interface designs.

In light of these developments, is common sense enough for designing effective operator interfaces? Experience has shown the answer to be no. The technical people who are so good at designing effective control algorithms and electronic circuits are not always trained in effective communication through an operator interface. Human factors guidelines are one way to introduce human factors principles into the design of equipment and interfaces. There is also real value in including human factors experts on the design team. In the end, attention to this area may be the determining factor in operator acceptance and the effective application of new control technologies.

ABSTRACT *Human factors is a discipline that focuses on the interactions between people and equipment. A longtime supporter of human factors research, EPRI has recently issued revised guidelines to help utilities incorporate human factors principles into the design of control rooms and operator interfaces for fossil fuel power plants. The revised guidelines are a response to sweeping advances in control room technology and CRT displays. Utility experience has already shown that the application of human factors engineering can increase plant safety, availability, and productivity.*

Misconceptions about human factors

Some of the common impressions people have about human factors are actually misconceptions. First, people sometimes suggest that human factors engineering is nothing more than using common sense. On the contrary, research on human performance often leads to unexpected results. For example, workers at one plant showed improved performance when lighting levels in their work area were increased, as common sense would suggest; however, when researchers subsequently decreased lighting levels, even to ridiculously low levels, worker performance continued to improve. (This response has been called the Hawthorne effect, after the plant where it was first observed.) Evidently, the attention paid to the workers led to the improved performance, even when the lighting levels were very low. Of course, these results do not imply that we can ignore lighting—the lesson is that common sense is not enough to understand the complex human interactions in the workplace.

Second, according to some people, human factors addresses trivial details, like the size of lettering on labels and the distance between control push buttons. Human factors engineers do address such details but do not consider them trivial. Since stress has a cumulative effect on human performance, minor annoyances can add up, producing performance problems in an emergency situation. Operators adapt remarkably well to unsupportive design factors, but the fewer annoyances they have, the more attention they can focus on managing the plant.

Third, human factors may seem to be concerned with just equipment—knobs and dials or display color and density. In fact, it goes beyond such issues to address operator decision-making and information needs. Modern equipment is becoming more complex, requiring the operator to do more complex information processing and decision making. The operator interface is a key link in the process of controlling a plant. It should not be considered independently but rather should be analyzed as part of the plant control process. For example, there is no screen design and color scheme that is best for all situations. It is important to first determine what decisions must be made with what information and then design displays to meet those requirements.

Fourth, contrary to common impression, not all the answers to human factors concerns can be found in a handbook or a guide. Although a guide is a good first step, situation-specific data and analysis are beneficial in all but the simplest applications. Quite often, design guidelines must be adapted to meet the needs of a given site. For example, a color-coding guideline might specify that each color have a unique meaning, such as blue for water lines. However, if the plant's display system has only eight or so distinguishable colors (which is usually the case even for displays with large color palettes), a specific color may have to be used in another context for a different meaning—for example, blue may also have to represent a trend line. Careful planning can reduce operator confusion and still use color coding to communicate information.

Control room design

Operator input and human factors guidelines provide a strong foundation for optimal equipment and operator-interface design. Reviewing preliminary drawings and mockups against human factors criteria early in the design stage helps to avoid costly backfits. Also, developing the display organization and control grouping strategy early on is important.

Some goals for the control room design process follow:

- Design facilities so that the environment supports system operation
- Place components so that operators can perform their jobs more efficiently and with less opportunity for error
- Position control devices to simplify operations
- Make control functions natural and easy to understand
- Use control devices that will withstand the rigors of operation

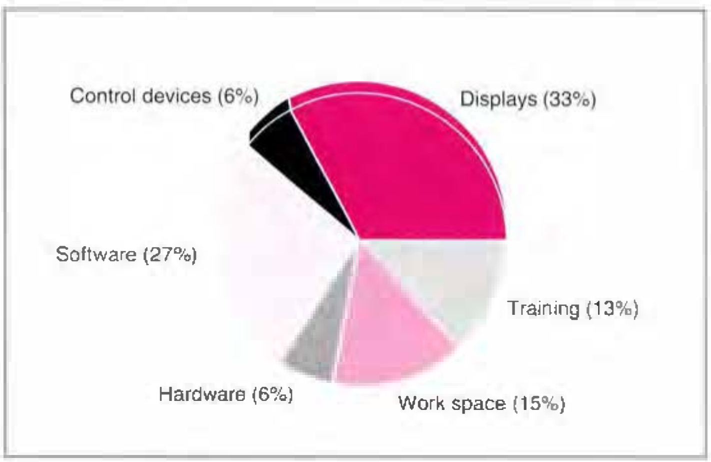


Figure 1 A utility that performed three control room upgrades without human factors guidance subsequently experienced problems in several areas. The greatest number of problems involved CRT displays. (Each area is shown as a percentage of the total number of problems reported.)

The recent human factors guidelines contain advice on control room design in two main categories: work space and equipment layout. The advice on work space covers climate, noise, lighting, physical access, visibility, traffic, console design, CRT workstation design, seating, desks, support facilities, and safety equipment. The advice on equipment layout covers push buttons, switches, rotary controls, multicontrol modules, control coding, visual displays, legend indicators, annunciator tiles, counters, analog meters, recorders, digital displays, auditory signals, alarms, and labeling.

Display design

Good displays provide relevant, easy-to-understand information to the operator. Experience shows that the proper use of color, display organization, control grouping strategy, and menu design can enhance operator performance.

The importance of human factors in designing effective operator interfaces is illustrated by the experience of one utility. After upgrading several control rooms without human factors assistance, the utility experienced problems in various areas, especially display technology (Figure 1). Here are examples of the utility's problems:

- System level: There were no displays for certain modes (e.g., startup); updates were not frequent enough to show trends; and operators lacked confidence in the reliability of displayed information.
- Screen hardware: Text-only display hardware was purchased when graphics capabilities would have been useful.
- Screen layout: Some displays were too dense (e.g., the mimic display of the burner and ignition fuel).
- Color: Certain colors, such as light blue and white, were not distinguishable from each other on some systems.
- Menu design: Unnecessarily long menus were a common problem. For example, long lists of instrument or valve numbers were presented in multipage menus without grouping to facilitate access.
- Information organization: The procedures for paging and scrolling in some systems were difficult to learn. Some displays did not indicate whether additional information was available on other displays.

Figure 2 This control system display example gives an overview of plant status. It uses color, graphs, and symbols to provide operators with a broad range of plant information on a single screen.

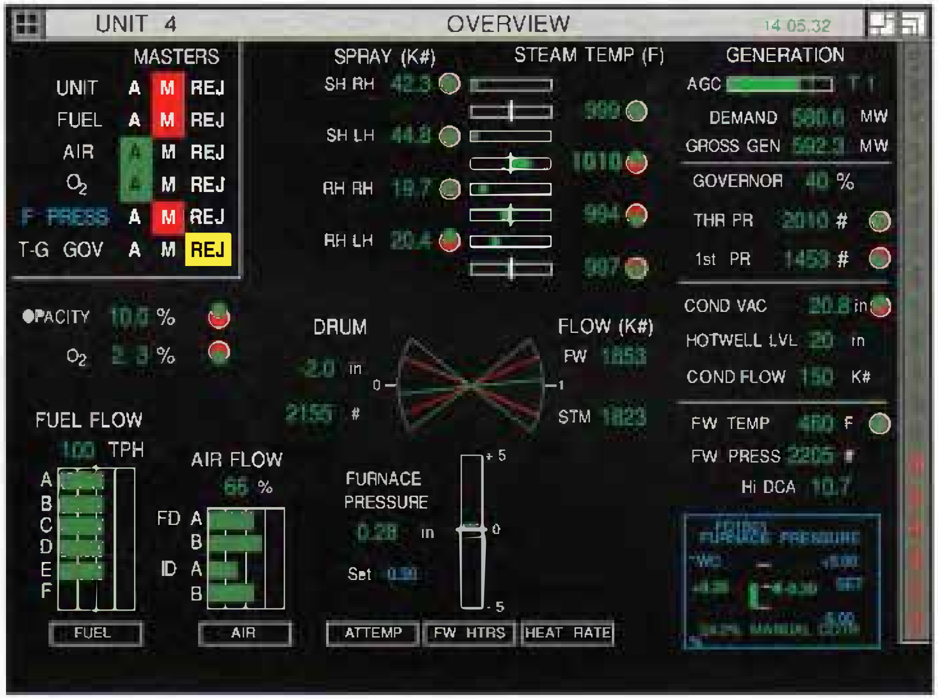


Table 1
GUIDELINES FOR CONTROL ROOM DISPLAYS

Area	Topics Covered
Overall system requirements	Response time, display of dynamic data
Screen structure and content	Fonts, character size, viewing distance, symbols, cursors, abbreviations and acronyms, labels, messages, error messages, alphanumeric codes, text, user aids, data entry
Screen organization and layout	Screen size, display density, grouping of information, display partitioning, placement and sequence of information, multipage considerations, interframe considerations
Color and other visual coding techniques	Color use and assignment, symbols and icons, geometric shapes, object size, line coding, brightness, blinking, contrast reversal, combination of codes
Menu design	General guidelines, format, item selection, menu hierarchy, supplements
Windows	General guidelines, real-time displays, dialogue boxes, alert boxes
Information format	General requirements, analog information, digital information, deviation bar graphs, range bars, column charts, cumulative bar charts, band charts, circular profiles, fourfold circular displays, line charts, trend plots, mimic displays, data maps, display enhancements
Alarms	General characteristics, auditory alerts, message content, alarm lists, alarm system controls, alarm reduction and prioritization, response to alarms
Input and control devices	Keyboards, trackballs, light pens, touch screens, mice
Control and display integration	User dialogue, system feedback, manual control stations, automatic control stations, mimic display of controls, permissives, tagouts, control of multiple CRTs with single keyboard
Hardware aspects	Luminance, glare, flicker, image polarity
Other	Hard-copy devices, large-screen displays

◻ Format: There were inconsistencies between component numbering on mimics and in tabular displays. The plant mimics had to be improved or combined to provide a better overall picture of plant operation.
◻ Alarms: Nuisance alarms and a lack of alarm sequence data were typical problems.
◻ Operator acceptance: Information was so difficult to retrieve that at some plants operators did not use the CRT control stations but instead went back to using hard controls.

The recent guidelines present detailed advice for remedying such problems, including a comprehensive survey of CRT display design (Table 1). The guidelines also include practical advice on promoting operator acceptance of new equipment and achieving performance improvements.

The human factors approach is especially useful in dealing with what is called the windowing effect—the decreased access to information associated with the switch to CRT-based operator interfaces. Large panels with all controls and displays visible have given way to CRT monitors that show only small windows of plant information. Operators may have trouble accessing information through multiple small windows. Human factors engineering can help avoid this problem while taking advantage of the vast communication potential of CRT displays (Figure 2).

Planning for human factors

A successful approach to incorporating human factors into control room upgrades is to apply the EPRI guidelines with the assistance of a human factors expert. Typically this starts with a survey of the existing control room and its environment. Checklists are developed on the basis of human factors criteria. Observations and measurements are made in the control room to plan for the new control system, with lighting and layout as key concerns. Systematic operator interviews are conducted to gather information about functions, tasks, and information requirements. These data are examined in light of the human factors guidelines to develop display requirements, system requirements, and a conceptual design. The conceptual design includes display organization, display characteristics, and control grouping strategy.

The bottom line

EPRI's human factors guidelines capture the experience of many fossil plants. They will help utilities avoid the problems experienced at some plants and will improve operator performance in advanced CRT-based control rooms. Common sense is not sufficient for designing and evaluating todays complex control room and plant environments. Explicit and systematic attention to human factors is required to meet the needs of control room operators.

EPRI is currently working with member utilities to demonstrate the use of the guidelines. Some of the utilities are designing new plants, and others are backfitting plants to upgrade old equipment or correct problems. A review of alarm displays at four units of one utility illustrates the benefits of this work. In a previous incident, 1700 alarms occurred in a two-hour period, and a component was damaged that cost the utility $1.5 million to repair. In another incident, a $50,000 motor had to be replaced because a critical alarm was on a back page and was not seen. A human factors expert evaluated the utility's situation and recommended measures that could prevent such problems in the future for about 1% of the cost of the incidents.

It is clear that control room equipment and operator interfaces are changing, with hard control panels becoming a thing of the past. In the transition to the new CRT-based technology, utilities will find human factors to be of increasing help. For additional information, contact Roy Fray at (415) 855-2441 or Mark DeCoster at (415) 855-2777.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Waste Treatment Projects: Technical Support (RP2662-50)	$67,100 12 months	Energy & Environmental Management/*M. Jones*
End-Use Power Quality Services: Technical Assistance and Coordination (RP2935-26)	$152,500 8 months	CRS Sirrine/*M. Samotyj*
Advanced Motor Drive Development Program Support (RP3087-27)	$177,400 11 months	Electrotek Concepts/*B. Banerjee*
Transfer of Electrotechnologies to Process Industry (RP3245-16)	$59,800 10 months	Jigar Shah & Associates/*A. Amarnath*
Process Optimization Techniques Methodology, Software, and Case Studies (RP3245-17)	$165,300 15 months	TENSA Services/*A. Amarnath*
Process Industry Analysis and Case Study Support (RP3245-19)	$173,400 14 months	Resource Dynamics Corp./*A. Amarnath*
Comparison of Strap-on Ultrasonic Flowmeters With In-line Flowmeters (RP3269-22)	$72,100 6 months	Geomet Technologies/*P. Hummel*
Guidelines for the Placement of Lighting Loggers (RP3269-23)	$89,000 12 months	Geomet Technologies/*P. Hummel*
G-Van Warranty and Service Organization (RP3272-7)	$101,400 12 months	Dynatech/*G. Purcell*
Food Service Uniform Test Procedures (RP3615-1)	$1,180,000 48 months	Pacific Gas and Electric Co./*K. Johnson*
Enhancement and Demonstration of MarketTREK's Marketing Mix Modeling Capabilities (RP3618-1)	$447,000 15 months	Research Triangle Institute/*P. Meagher*
The Single-Phase "Written Pole" Large-Horsepower Motor for Low-Voltage Systems (RP3636-1)	$450,000 12 months	Precise Power Corp./*B. Banerjee*
Monitoring of Commercial Cool Storage Systems (RP3650-1)	$106,200 16 months	University of Central Florida/*R. Wendland*
Electric Motor Repair Industry Assessment (RP3673-1)	$231,500 29 months	Washington State Energy Office/*B. Banerjee*
Electrical Systems		
Distribution Automation Demonstration (RP2592-14)	$1,066,000 36 months	Northern States Power Co./*B. Blair*
Development of Improved Prototype Cable Fault Locator (RP2895-6)	$141,400 14 months	Edison Control Corp./*H. Ng*
Economic Impacts of Distribution System Power Quality Variations (RP3389-11)	$187,200 10 months	Electrotek Concepts/*H. Mehta*
Development and Demonstration of Distribution STATCON (Static Condenser) (RP3389-12)	$854,800 36 months	Westinghouse Electric Corp./*H. Mehta*
Evaluation of Emerging Scheduling Methods for RSC (Resource Scheduling and Commitment) Program (RP3555-2)	$196,800 9 months	EPIC Engineering/*G. Cauley*
New Control Objectives and Valuation of Control/Unit Dispatchability (RP3555-3)	$149,600 12 months	Zadeh Meyer Engineering/*G. Cauley*
Substation Insulators (RP3684-1)	$840,000 36 months	University of New Orleans/*J. Hall*
Cable Pushing and Calculation of Pulling Tensions for Distribution and Transmission Cables (RP7910-19)	$628,200 24 months	Underground Research/*T. Rodenbaugh*
Environment		
PISCES Field Chemical Emissions Monitoring at Niagara Mohawk's Oswego Unit 6 (RP3177-19)	$570,100 11 months	Carnot/*B. Toole-O'Neil*
Development of Reactive Plume and Optics Models (RP3218-5)	$459,400 15 months	ENSR Corp./*P. Saxena*
Atmospheric Reaction of Water-Soluble Mercury (RP3218-6)	$129,900 24 months	Frontier Geosciences/*D. Porcella*
Experimental Studies of Residential Transients (RP3349-5)	$75,000 11 months	General Electric Co./*R. Kavet*
Mouse Skin Cancer Study: Technical Assistance (RP3349-6)	$66,000 23 months	Dermigen/*R. Kavet*
Association of Wire Code Configurations With Long-Term Average 60-Hz Magnetic Fields and Exposures (RP3533-1)	$424,000 13 months	T. Dan Bracken, Inc./*R. Kavet*
Wetlands Ecology and Management Model (RP35[illegible]1-2)	$140,100 10 months	Tetra Tech/*D. Porcella*
Pilot Pulse-Jet Baghouse Evaluation at the Homer City Station: Site Management (RP3607-1)	$200,000 15 months	Pennsylvania Electric Co./*R. Chang*
Pilot Pulse-Jet Baghouse Evaluation at the Homer City Station: Testing (RP3607-2)	$171,800 12 months	ADA Technologies/*R. Chang*
Ozone Formation: Study of Volatile Organic Compounds and Nitrogen Oxides (RP3626-1)	$496,100 21 months	Empire State Electric Energy Research Corp./*D. Hansen*
Assessment of Lung Health and Risk After Respirable Fiber Exposure (RP3627-1)	$1,200,000 37 months	Case Western Reserve University/*L. Goldstein*
Survey of Low-NO_x-Burner Technology for Gas/Oil-Fired Boiler Application (RP3631-1)	$55,200 6 months	Energy Technology Consultants/*K. Zammit*
Exploratory & Applied Research		
Solvent Permeation, Swelling Profiles, and Mechanical Properties of Thin Polymer Films (RP8019-2)	$145,000 36 months	Lehigh University/*B. Bernstein*
Oxidative Reactions of Sulfur Forms in Coal (RP8022-1)	$150,000 15 months	Iowa State University/*W. Weber*
Advanced Surface Modification Using Plasma Methods (RP8042-3)	$5[illegible]1,800 36 months	DOE/*J. Stringer*
Advanced Materials for High-Temperature Fuel Cells (RP8062-2)	$375,000 40 months	Argonne National Laboratory/*R. Goldstein*
Analysis of Boiler Tube Failures: Theory and Practice (RP9000-22)	$94,100 13 months	Cornice Engineering/*B. Dooley*
Turbine Steam Chemistry and Corrosion (RP9003-1)	$235,200 24 months	Jonas, Inc./*B. Dooley*
Generation & Storage		
Pilot Plant Assessment of Coal Blend Properties and Their Impact on Critical Power Plant Components (RP2425-12)	$110,000 18 months	University of North Dakota/*A. Mehta*
Air Heater Analysis and Operation (RP2504-14)	$63,900 9 months	Cornice Engineering/*B. Dooley*
Benefit Assessments for Superconducting Magnetic Energy Storage (RP2572-13)	$150,000 12 months	Battelle, Pacific Northwest Laboratories/*R. Schainker*
Handbook for Fossil Plant Control System Improvements (RP2710-30)	$89,400 12 months	PowerGen/*J. Weiss*
Guidelines for Conversion From Coal and Oil Firing to Gas Firing (RP2819-23)	$99,700 13 months	Stone & Webster Engineering Corp./*E. Petrill*
EPRI/Grimethorpe Ash/Filter Tests (RP3161-7)	$54,700 15 months	Westinghouse Electric Corp./*R. Brown*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Generation & Storage (cont.)		
Coproduction Power Plant Study (RP3226-7)	$228,600 11 months	Hawaiian Electric Company/N. Stewart
Estimated Development Schedule and Costs for a Heavy-Frame Hot-Air Turbine (RP3251-4)	$56,500 4 months	Westinghouse Electric Corp./A. Cohn
Compressed-Air Energy Storage Porous-Media Reservoir Simulator Development Plan (RP3390-2)	$74,300 10 months	Fairchild, Ancell & Wells/B. Mehta
Real-Time On-line Monitoring and Diagnostic System (RP3485-20)	$60,600 15 months	Stone & Webster Engineering Corp./R. Colsher
Monitoring of General Electric Dry Low-NO$_x$ Combustor (RP3488-1)	$1,120,000 43 months	Jersey Central Power & Light Co./H. Schreiber
Combustion Emissions Model and Software (RP3489-1)	$[illegible]12,000 34 months	Carnot/W. Rovesti
PVUSA Performance Evaluation: Kerman Installation (RP3490-2)	$600,000 15 months	Pacific Gas and Electric Co./F. Goodman
Bioremediation of Organic-Contaminated Soils: Evaluation and Research Needs Assessment (RP3518-1)	$400,000 24 months	Southern Company Services/S. Yunker
Vibration Monitoring and Analysis System (RP3535-1)	$535,500 17 months	Southwest Research Institute/C. Dohner
Integrated Energy Systems		
New Methods of Technology Assessment (RP1[illegible]78-29)	$74,[illegible]00 12 months	National Economic Research Associates/G. Ramachandran
Integrated Resource Planning: Development of IRP-Manager Database (RP2807-11)	$300,000 1[illegible] months	Electric Power Software/J. Bloom
Comprehensive Electrical Systems Planning (RP3581-3)	$298,500 14 months	University of Texas, Austin/G. Gross
Enhancement of ContractMix for Uranium Users (RP3604-1)	$98,600 11 months	Decision Focus/C. Clark
Nuclear Power		
Wireless Programmable Process-Monitoring System (RP240[illegible]-14)	$78,100 14 months	Battelle Memorial Institute/R. James
Guidelines for Instrument Calibration Extension/Reduction Programs (RP2409-21)	$73,700 [illegible] months	Edan Engineering Corp./R. James
Condensate Polishing: Materials, Systems, and Operations (RP2414-58)	$99,200 12 months	Puricons/C. Hornibrook
Reliability-Centered Maintenance for Transmission and Distribution (RP2970-11)	$55,200 5 months	Halliburton NUS Corp./D. Worledge
Analysis of Events Potentially Leading to Severe Accidents (RP3012-4)	$51,600 10 months	Gabor, Kenton & Associates/E. Fuller
Energy Production Systems From Heat Produced in Deuterated Metals (RP3170-23)	$5,013,000 32 months	SRI International/T. Passell
Theoretical Research on Neutron Transfer Reactions (RP3170-25)	$100,400 12 months	Massachusetts Institute of Technology/T. Passell
Decommissioning Program Development Coordination (RP3171-3)	$116,800 15 months	J. E. Cline & Associates/C. Hornibrook
Probabilistic Safety Assessment In-plant Communication (RP3200-12)	$120,000 9 months	Erin Engineering & Research/J. Sursock
Functional Specifications for Instrumentation and Control Upgrades (RP3208-4)	$68,000 8 months	Capri Technology/A. Machiels
Browns Ferry Network Architecture Plan (RP3332-4)	$60,800 10 months	Capri Technology/R. Torok
Qualification of Commercially Available Programmable Logic Controllers for Use in Safety-Related Class 1E Applications (RP3406-1)	$356,200 13 months	Westinghouse Electric Corp./J. Naser

Project	Funding/ Duration	Contractor/EPRI Project Manager
Oxidation Induction Time Cable Test (RP3427-2)	$61,600 12 months	University of Virginia/J. Carey
Rate-of-Loading Separate Effects Testing (RP3433-12)	$363,300 16 months	Battelle Memorial Institute/K. Wolfe
Friction Separate Effects Testing (RP3433-13)	$371,800 16 months	Battelle Memorial Institute/K. Wolfe
Motor-Operated Valve System Flow Model (RP3433-25)	$95,900 12 months	ABB Impell Corp./K. Wolfe
Butterfly Valve Testing (RP3433-31)	$249,400 6 months	Kalsi Engineering/K. Wolfe
Severe-Accident Analysis Workstation Structural Software Specification (RP3481-1)	$105,300 6 months	Erin Engineering & Research/J. Chao
Sludge Transport Model (RP3500-16)	$127,400 15 months	Atomic Energy of Canada/B. Chexal
Development of Shape-Memory-Material Tube Sleeves for PWR Steam Generators (RP3500-19)	$86,200 12 months	Dominion Engineering/P. Paine
CHECWORKS Demonstration (RP3528-1)	$549,900 29 months	Altos Engineering Applications/R. Mahini
Outage Risk Assessment and Management Package for Implementation in ANO Units 1 and 2 (RP3531-1)	$467,500 17 months	Erin Engineering & Research/P. Kalra
Operational Requirements for Modular High-Temperature Gas-Cooled Reactor Plant (RP3630-1)	$81,400 3 months	Gas-Cooled Reactor Associates/T. Marston
Ultrasonic Guided-Wave Inspection of Steam Generator Tubing (RP3[illegible]87-1)	$325,800 24 months	Pennsylvania State University/M. Avioli
Known Substitute Materials for Use in Nuclear Plants (RP3800-17)	$166,800 7 months	Radian Corp./C. Hornibrook
Low-Level Radioactive Waste Storage and Disposal (RP3801-1)	$224,000 14 months	Boston Edison Co./C. Hornibrook
Steam Generator Databases (RPS405-19)	$54,400 8 months	Adams & Hobart/P. Paine
Inhibition of IGA/SCC on Alloy 600 Surfaces Exposed to PWR Secondary Water (RPS407-53)	$860,100 31 months	Commissariat à l'Energie Atomique/P. Paine
Plugging Limits for Outside-Diameter Stress Corrosion Cracking at Tube Support Plate Intersections of PWR Steam Generators (RPS414-2)	$335,500 24 months	Westinghouse Electric Corp./C. Williams
Technical Support for Tube Support Plate Tube-Plugging Criteria Limits (RPS414-3)	$87,200 14 months	Westinghouse Electric Corp./C. Williams
Steam Generator Tube Fatigue Analysis (RPS415-2)	$398,900 30 months	Foster Wheeler Development Corp./G. Srikantiah
Inspection of Retired NYPA Steam Generator: Ruptured-Tube Causative Mechanism Evaluation (RPS415-4)	$430,400 15 months	Westinghouse Electric Corp./G. Srikantiah
CREV-SIM Application at Millstone Unit 2 (RPS416-7)	$121,200 11 months	NWT Corp./P. Millett
CREV-SIM Application at Duke Power (RPS416-8)	$61,100 11 months	NWT Corp./P. Millett
Low-Volatility pH Control Systems for Steam Generators (RPS510-1)	$100,800 14 months	San Diego State University Foundation/P. Paine
Effect of Inhibitors on Surface Film Electric Resistance of Alloy 600 (RPS511-1)	$219,400 23 months	VTT (Technical Research Centre of Finland)/P. Paine
Development of Videotape Training Program for the Seismic Qualification Utility Group (RPS801-11)	$593,200 11 months	Industrial Training Corp./R. Kassawara
Examination of SPC Grohnde Fuel Assemblies After Third Irradiation Cycle (RPX103-10)	$74,000 5 months	Siemens Power Corp./S. Yagnik
Fuel Degradation Test Project (RPX103-20)	$1,489,800 45 months	Institutt for Energiteknikk/B. Cheng

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

Electro-Osmosis Effectiveness in Reducing Tillage Draft Force and Energy Requirements
TR-100446 Final Report (RP2782-4); $200
Contractors: University of Arizona; National Food and Energy Council
EPRI Project Managers: A. Amarnath, O. Zimmerman

Electrical Separation of Protein Concentrate From Juice of Forages
TR-100970 Final Report (RP2782-4); $200
Contractors: USDA–Agricultural Research Service; University of Wisconsin; National Food and Energy Council
EPRI Project Managers: A. Amarnath, O. Zimmerman

Assessment of the Market Potential for the Brushless Doubly-Fed Machine (BDFM)
TR-101829 Final Report (RP3087-8); $200
Contractor: Oregon State University
EPRI Project Manager: B. Banerjee

Commercial Building Water-Loop Heat Pump Field Test
TR-101865 Final Report (RP2480-1); $200
Contractor: Climate Master, Inc.
EPRI Project Managers: M. Khattar, M. Blatt

National Committee on Power Electronics: Report on Power Electronics and Global Competitiveness
TR-101899 Final Report (RP2918-2); $200
Contractor: University of Wisconsin, Madison
EPRI Project Manager: B. Banerjee

Water and Wastewater Industries: Characteristics and DSM Opportunities
TR-102015 Final Report (RP2662-10, RP3046-3); $200
Contractors: Burton Environmental Engineering; RCG/Hagler, Bailly, Inc.; Metcalf & Eddy, Inc.
EPRI Project Managers: M. Jones, P. Meagher

Proceedings: 6th National Demand-Side Management Conference—Making a Difference
TR-102021 Proceedings (RP3084-15); $200
Contractors: Barakat & Chamberlin, Inc.; Pacific Consulting Services
EPRI Project Manager: P. Hanser

Market Infrastructure and Compact Fluorescent Lamps
TR-102120 Final Report (RP2597-31, RP3249); $200
Contractor: Macro Consulting, Inc.
EPRI Project Managers: J. Kesselring, M. Evans

Volatile Organic Compound Recovery by Brayton Cycle Heat Pump
TR-102130 Final Report (RP2783-18); $200
Contractor: Southern California Edison Co.
EPRI Project Manager: A. Amarnath

High-Yield Pulping Effluent Treatment Technologies
TR-102131 Final Report (RP2782-7); $200
Contractor: Georgia Institute of Technology
EPRI Project Manager: A. Amarnath

Performance Evaluation of Refrigerant Mixtures in Heat Pumps
TR-102167 Final Report (RP2792-9); $200
Contractor: National Institute of Standards and Technology
EPRI Project Manager: P. Joyner

ELECTRICAL SYSTEMS

Large Locked Castings Using Expanding Monomer Modified Polysil™
TR-101707 Final Report (RP7919-1); license required
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: B. Bernstein

Proceedings: Substation Magnetic Field Management Workshop
TR-101852 Proceedings (RP2942-41); $200
Contractor: Electric Research & Management, Inc.
EPRI Project Manager: G. Addis

Voltage Stability/Security Assessment and On-Line Control, Vols. 1–4
TR-101931 Final Report (RP3040-1); Vols. 1–4, $200 each volume
Contractors: Ontario Hydro; Michigan State University
EPRI Project Manager: D. Maratukulam

Magnetic Replicas and the Very Incomplete Meissner Effect
TR-102316 Final Report (RP4000-23); $200
Contractor: University of Houston
EPRI Project Manager: M. Rabinowitz

ENVIRONMENT

Detailed Physical, Chemical, and Mineralogical Analyses of Selected Coal and Oil Combustion Ashes
TR-101785 Final Report (RP2485-8); $200
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Managers: I. Murarka, A. Quinn

Polychlorinated Biphenyl Substitutes in Electric Utility Equipment
TR-102160 Interim Report (RP2879-19); $200
Contractor: SRF Environmental and Health Management, Inc.
EPRI Project Manager: J. Goodrich-Mahoney

Biodegradability of Pentachlorophenol in the Environment: A Literature Review
TR-102172 Final Report (RP2879-6); $200
Contractor: Remediation Technologies
EPRI Project Manager: I. Murarka

Development and Implementation of a Variable Infiltration Capacity Model of Surface Hydrology Into the General Circulation Model
TR-102243 Final Report (RP2938-3); $200
Contractors: University of Washington; Princeton University
EPRI Project Manager: D. McIntosh

EXPLORATORY & APPLIED RESEARCH

Exploratory Research to Implement DYNAC in a Parallel Processing Environment
TR-102076 Final Report (RP8004-20); $200
Contractor: S. Levy, Inc.
EPRI Project Manager: J. Weiss

Proceedings: Microwave-Induced Reactions Workshop
TR-102252 Proceedings (RP8060-99); $200
Contractor: Meeting Planning Associates
EPRI Project Managers: R. Weaver, A. Amarnath

Measurement of pH and Potential in Supercritical Water, Vols. 1 and 2
TR-102277 Final Report (RP8002-18); Vol. 1, $200; Vol. 2, forthcoming
Contractor: SRI International
EPRI Project Managers: B. Dooley, B. Syrett

GENERATION & STORAGE

Atmospheric Fluidized-Bed Combustion Balance-of-Plant Reference Manual
TR-100575 Final Report (RP3162-5, -6, -7, -8); $200
Contractors: D. Thimsen; Power Tech Associates, P.C.; Joseph Technology Corp., Inc.; Fluidized-Bed Technologies, Inc.
EPRI Project Manager: T. Boyd

Cost-Effective Photovoltaic-Powered Transmission and Distribution Sectionalizing Switches
TR-100712 Final Report (RP1975-8); $200
Contractor: Ascension Technology, Inc.
EPRI Project Manager: J. Bigger

Coal Cleaning Cost Model
TR-101025 Final Report (RP1400-6); $200
Contractor: ICF Kaiser Engineers, Inc.
EPRI Project Manager: D. O'Connor

New Techniques and Data Sources for Probable Maximum Precipitation, Vols. 1–4
TR-101242 Final Report (RP3113-1); Vols. 1 and 2, $200 each volume; Vols. 3 and 4, forthcoming
Contractor: Climatological Consulting Corp.
EPRI Project Manager: D. Morris

HOT FOIL™ Instrument for Measuring the Coking Index of Residual Oils
TR-101662 Topical Report (RP2778-14); $200
Contractors: Fossil Energy Research Corp.; Electric Power Technologies, Inc.
EPRI Project Manager: W. Rovesti

Wastewater Treatment Manual for Coal Gasification–Combined-Cycle Power Plants, Vols. 1–3
TR-101788 Final Report (RP2526-1); Vols. 1–3, $600 for set
Contractor: CH2M Hill
EPRI Project Manager: M. Epstein

Houston Lighting & Power Company's Evaluation of Coal Gasification Coproduction Energy Facilities
TR-101789 Final Report (RP3226-4); $200
Contractor: Houston Lighting & Power Co.
EPRI Project Manager: M. Epstein

Conference Proceedings: Application of Fluidized-Bed Combustion for Power Generation
TR-101816 Proceedings (RP3167); $200
EPRI Project Managers: T. Boyd, J. Wheeldon

Fiber-Optic Distributed Temperature Sensor Demonstration
TR-101950 Final Report (RP2487-2); $200
Contractor: Battelle
EPRI Project Manager: J. Stein

Proceedings of the 1992 EPRI Heat Rate Improvement Conference
TR-102098 Proceedings (RP1711); $200
Contractor: Sargent & Lundy
EPRI Project Manager: R. Leyse

Heat Rate Demonstration Project, Mt. Storm Unit 1
TR-102127 Final Report (RP2818-3); $200
Contractors: Virginia Power Co., Black & Veatch, Engineers-Architects
EPRI Project Manager: R. Leyse

Performance and Reliability of Solar Progress Photovoltaic Plant, 1990–1991
TR-102168 Final Report (RP1607-14); $200
Contractor: Florida Solar Energy Center
EPRI Project Manager: J. Berning

Experiences With Commercial Wind Energy Development in Hawaii
TR-102169 Final Report (RP1590-10); $200
Contractor: R. Lynette & Associates, Inc.
EPRI Project Managers: J. Berning, J. Schaefer

INTEGRATED ENERGY SYSTEMS

Proceedings: Fifth Annual Executive Conference on Utility Strategic Asset Management
TR-102041 Proceedings (RP3678); $200
Contractor: American Productivity and Quality Center
EPRI Project Manager: L. Rubin

Principles of Business Unit Income Reporting for Electric Power Companies
TR-102042 Final Report (RP2074-1); $200
Contractor: Mercer Management Consulting
EPRI Project Managers: H. Mueller, L. Rubin

Technology Transfer and Innovation in the Utility Organization: A Workbook
TR-102445 Final Report (RP3220-3); $1000
Contractor: Nilo Lindgren
EPRI Project Manager: J. Oggerino

NUCLEAR POWER

FREY-01: Fuel Rod Evaluation System, Vols. 1–4, Revision 2
NP-3277 (Rev. 2) Final Report (RP1117-5, RP1321-4); Vol. 1, $200, Vols. 2 and 3, license required; Vol. 4, forthcoming
Contractor: Anatech Research Corp.
EPRI Project Manager: L. Agee

Storage and Handling of Fuel Oil for Standby Diesel Generator Systems, Revision 1: A Guide for Nuclear Power Plant Maintenance Personnel
NP-6314 (Rev. 1) Final Report (RP2814-3, -66); $8400
Contractor: Southwest Research Institute
EPRI Project Manager: W. Johnson

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

Integrated Instrumentation and Control Upgrade Plan (Revision 3)
NP-7343 (Rev. 3) Topical Report (RP3114-59); $200
Contractors: Mollerus Engineering Corp.; Science Applications International Corp.
EPRI Project Manager: C. Wilkinson

Circuit Breaker Maintenance, Vol. 1, Part 4: Low-Voltage Circuit Breakers, Westinghouse DS Models
NP-7410 Final Report (RP2814-61); Vol. 1, Part 4, $10,800
Contractor: Grove Engineering, Inc.
EPRI Project Manager: J. Sharkey

Structural Design of Concrete Storage Pads for Spent-Fuel Casks
NP-7551 Final Report (RP2813-28); $200
Contractor: Anatech Research Corp.
EPRI Project Manager: R. Williams

Proceedings: EPRI Workshop 1—Technical Basis for EPA HLW Disposal Criteria
TR-100347 Proceedings (RP3294-1); $200
Contractor: Rogers and Associates Engineering Corp.
EPRI Project Manager: R. Williams

Development of a Hydrogen Monitor for High-Temperature and High-Pressure Aqueous Systems
TR-100788 Topical Report (RP2816-1); $200
Contractor: AECL Research
EPRI Project Manager: T. Passell

Guideline for Using Items Manufactured to Other Industry Standards in Nuclear Safety–Related Applications
TR-101752 Final Report (RPQ101-44); $200
Contractor: Sargent & Lundy
EPRI Project Managers: T. Mulford, F. Rosch

Condensate Polishing Guidelines for PWR and BWR Plants
TR-101942 Final Report (RP2977); $200
EPRI Project Managers: P. D'Angelo, T. Passell

Evaluation of Reactor Pressure Vessel Head Cracking in Two Domestic BWRs
TR-101971 Final Report (RPC102-12); $1000
Contractor: Structural Integrity Associates
EPRI Project Manager: R. Pathania

Stability of a Fiber-Optic pH Sensor at 100°F
TR-101972 Final Report (RP8004-2); $200
Contractor: Lawrence Livermore National Laboratory
EPRI Project Manager: T. Passell

Photosonic Digestion of Aqueous Organics
TR-101974 Final Report (RP2977-4); $200
Contractor: Carter Analytical Laboratory, Inc.
EPRI Project Manager: T. Passell

Workbook for Maintenance Proficiency Testing
TR-101981 Final Report (RP2705-10); license required
Contractor: Anacapa Sciences, Inc.
EPRI Project Manager: J. Yasutake

Characterization of Microstructure and IGSCC of Alloy 600 Steam Generator Tubing
TR-101983 Final Report (RPS303-10, -26; RPS404-13); $200
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: A. McIlree

Application of a Cost-Benefit Analysis Methodology to Nuclear I&C System Upgrades
TR-101984 Final Report (RP3373-5); license required
Contractor: Decision Focus, Inc.
EPRI Project Managers: S. Oh, C. Lin

BWR Fuel Consolidation: A System Design
TR-101985 Final Report (RP3100-2); $200
Contractor: Nuclear Assurance Corp.
EPRI Project Manager: R. Lambert

Boraflex Test Results and Evaluation
TR-101986 Interim Report (RP2813-4); $200
Contractor: Northeast Technology Corp.
EPRI Project Manager: R. Lambert

Relationship of Radiation-Induced Segregation Phenomena to Irradiation-Assisted Stress Corrosion Cracking (IASCC)
TR-101987 Final Report (RPX102-2); license required
Contractor: Westinghouse Science and Technology Center
EPRI Project Manager: J. Nelson

Feasibility Evaluation of the Universal Container System: A Multipurpose Standardized Spent-Fuel Container System
TR-101988 Final Report (RP2717-14); $200
Contractor: E. R. Johnson Associates, Inc.
EPRI Project Manager: R. Williams

Experimental Residual Stress Evaluation of a Section of Clad Pressure Vessel Steel
TR-101989 Final Report (RPC102-7); $100
Contractors: PROSIG, Inc.; EPRI Nondestructive Evaluation Center
EPRI Project Manager: R. Pathania

EPRI Events

SEPTEMBER

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

13–14
Measurement of Power System Magnetic Fields
Lenox, Massachusetts
Contact: Mary Fitzgerald, (413) 494-4359

14
Impact of Global Climate Change on Electric Utilities
St. Louis, Missouri
Contact: Susan Marsland, (415) 855-2946

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

16–17
Operational Reactor Safety Engineering and Review Group Workshop
Baltimore, Maryland
Contact: Susan Bisetti, (415) 855-7919

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

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

27–29
AMP–EEI Fall Conference (focus on electrotechnology case studies)
West Palm Beach, Florida
Contact: Leslie Niday, (614) 846-7322

27–October 1
4th International Conference on Batteries for Energy Storage
Berlin, Germany
Contact: Steve Eckroad, (415) 855-1066

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

OCTOBER

7–8
Repowering With Gas Turbines
Danvers, Massachusetts
Contact: Barry McDonald, (714) 259-9520

13–15
Fuel Supply Seminar
Tampa, Florida
Contact: Susan Bisetti, (415) 855-7919

19–21
Fossil Plant NDE
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

20–22
Meeting Customer Needs With Heat Pumps
New Orleans, Louisiana
Contact: Pam Turner, (415) 855-2010

26
Air Toxics R&D Results
Cleveland, Ohio
Contact: Denise O'Toole, (415) 855-2259

26–28
Fossil Plant Construction
Palm Beach, Florida
Contact: Lori Adams, (415) 855-8763

27
Air Toxics R&D Results
Atlanta, Georgia
Contact: Denise O'Toole, (415) 855-2259

27–28
Annual Fuel Oil Utilization Workshop
Baltimore, Maryland
Contact: Stephanie Drees, (714) 259-9520

27–29
12th Coal Gasification Power Plants Conference
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

28
Air Toxics R&D Results
Denver, Colorado
Contact: Denise O'Toole, (415) 855-2259

NOVEMBER

5
Municipal Water and Wastewater Conference
Seattle, Washington
Contact: Keith Carns, (510) 262-9506

7–12
International Conference on Photochemical Measurement and Modeling Studies
San Diego, California
Contact: Pam McCalla, (412) 232-3444

8–11
4th Annual Seminar on Decision Analysis for Utility Planning
San Diego, California
Contact: Katrina Rolfes, (415) 854-7101

9
Low-Level-Waste Training Courses
Monterey, California
Contact: Linda Nelson, (415) 855-2127

10–12
International Low-Level-Waste Conference
Monterey, California
Contact: Linda Nelson, (415) 855-2127

15–18
International Conference on Fossil Plant Simulators, Modeling, and Training
New Orleans, Louisiana
Contact: Susan Bisetti, (415) 855-7919

16–19
1993 Power Quality Applications/ Power Electronics Conference and Exhibit
San Diego, California
Contact: Carrie Koeturius, (510) 525-1205

19
2d International Seminar on Subchannel Analysis
Palo Alto, California
Contact: Lance Agee, (415) 855-2106

DECEMBER

1–3
2d National Electric Vehicle Infrastructure Conference
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

6–9
4th International Conference on Cold Fusion
Maui, Hawaii
Contact: Linda Nelson, (415) 855-2127

7–9
Utility Motor and Generator Predictive Maintenance Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

8–9
6th Annual Conference on Utility Strategic Asset Management
St. Petersburg, Florida
Contact: Lori Adams, (415) 855-8763

8–10
Efficient Lighting Symposium
Scottsdale, Arizona
Contact: David Ross, (703) 742-8402

8–10
Expert Systems Applications for the Electric Power Industry
Phoenix, Arizona
Contact: Jouni Keronen, (415) 855-2020

JANUARY 1994

18–20
Fossil Plant Inspections
San Antonio, Texas
Contact: Lori Adams, (415) 855-8763

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9–11
Innovative Electricity Pricing
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Contact: Pam Turner, (415) 855-2010

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