EMF and Utility Workers

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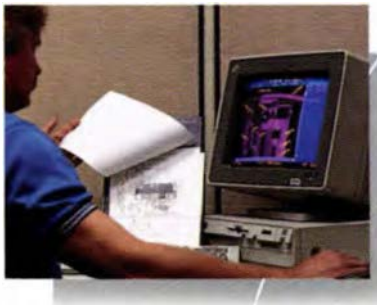

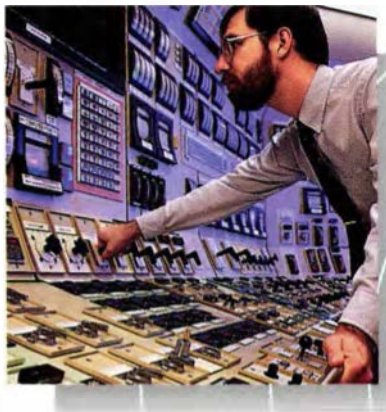

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Cover: Three major studies of cancer and magnetic field exposure included information on nearly 400,000 electric utility personnel working in a wide variety of jobs.

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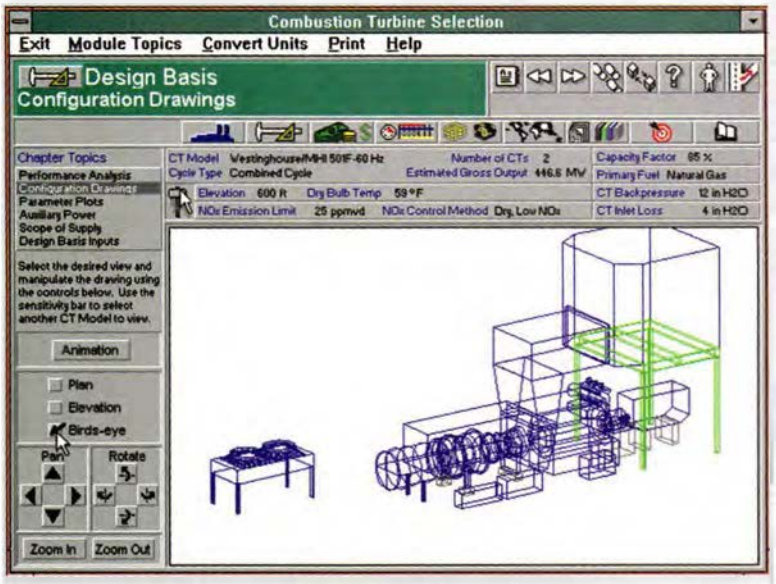

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POWER•COR Software Series

Corrosion problems are prevalent in a variety of electric generating systems. Diagnosing and resolving these problems can be challenging, given the torrent of information currently available. The POWER•COR series of software programs is designed to help demystify corrosion problems. The series offers utilities a single source of information—a source that enables the swift resolution of corrosion problems without the help of an expert. Currently, there are six modules in the POWER•COR series, all of which employ a user-friendly, menu-driven format with the option of color screens. For more information, contact Barry Syrett, (415) 855-2956. To order, call the Electric Power Software Center, (800) 763-3772.

MICPro, Version 2.0

MICPro is an expert system that gives utility personnel a rapid way to predict the susceptibilities of nuclear and fossil power systems and components to microbiologically influenced corrosion and abiotic corrosion. Version 2.0 allows the user to more easily evaluate the effectiveness of various methods of controlling both types of corrosion.

FGD•COR

FGD•COR guides utility engineers in the selection of corrosion-resistant construction materials for wet flue gas desulfurization systems. The module includes a failure analysis advisor that helps users identify the type and cause of corrosion or deterioration experienced. The advisor can also suggest preventive treatments for the type of corrosion identified.

CONDENSER•COR

This hypertext module can be used to analyze the failure of either freshwater or saltwater condenser components. Packed with a variety of corrosion data for common component materials in fossil and nuclear plants, CONDENSER•COR also can serve as a materials selection guide or be used to prescribe corrosion control options.

EDEAC-PC

EPRI developed EDEAC-PC to help utilities determine fatigue crack growth rates for various structural materials in nuclear power plants. The program contains data from over 1900 fatigue crack growth tests on ferritic steels, stainless steels, and nickel-base alloys in air, high-purity water, boiling water reactor, and pressurized water reactor environments.

SW•COR

This module helps utility engineers select the appropriate construction materials for piping and heat exchangers in power plant service water systems. SW•COR can help users identify and understand the mechanisms of failure in existing components of nuclear and fossil plants. The program also provides advice on how to prevent or minimize failures.

SCC/IGA-600

SCC/IGA-600 serves as a guide for assessing and tracking stress corrosion cracking and intergranular attack in Alloy 600 steam generator tubing in pressurized water reactor secondary-side water. An important feature of this program is its ability to record and track the number of tube failures in the user's own steam generators.

Magnetic Fields May Forewarn of Earthquakes

The ability to predict earthquakes has long been the Holy Grail of seismologists around the world and a topic of deep fascination for the general public. Every year, it seems, somebody comes up with a new theory about how to tell when the Big One might strike. Strange animal behavior and irregular geyser activity are just two of the more offbeat theoretical harbingers that have surfaced.

The theories with the most credibility, of course, are those based on scientific fact. One such theory, well publicized after California's 7.1 Loma Prieta temblor of October 1989, has drawn much attention from respected seismologists: the amplitudes of the earth's naturally occurring magnetic fields have been observed to significantly increase directly before large earthquakes.

According to Antony Fraser-Smith, a Stanford University professor of electrical engineering and geophysics who is among the scientists in the United States and elsewhere currently researching this phenomenon, such magnetic field fluctuations have been observed as much as a month before an earthquake. These fluctuations are sometimes followed by an additional variation only a few hours in advance of the event. So far, significant fluctuations—in most cases, more than double or triple the normal magnetic field amplitudes—have been observed in eight earthquakes, including the great Alaskan quake of 1964, the devastating Armenian quake of 1988, and the Loma Prieta quake.

Fraser-Smith, who collected magnetic field data from the Loma Prieta earthquake, reports that his readings were up to 300 times the amplitudes normal for the region. As he explains, he captured the readings by chance while recording magnetic field data for the U.S. Navy in an area that happened to lie just 3 miles from the quake's epicenter. Magnetic field data from the seven other sites were captured at greater distances from the epicenters, he notes.

In order to obtain accurate data, Fraser-Smith says, it is necessary to sift out the magnetic fields that don't occur naturally, such as those generated by cars and buses. That is precisely what he intends to do in a current EPRI-sponsored research project that will help establish a comprehensive monitoring system on the Hayward Fault, a 31-mile geologic fracture that runs through heavily populated areas east of San Francisco Bay.

According to Allan Lindh, a seismologist with the U.S. Geological Survey, the Hayward Fault is geologically very similar to the fault that caused the 7.0-magnitude temblor that devastated Kobe, Japan, in January. And given that the Hayward Fault runs through urban areas inhabited by 6 million people, the impact could be just as severe.

Researchers plan to establish a monitoring station near Lake Chabot, located east of San Francisco Bay, by April. Then, says Fraser-Smith, "It's just a matter of time." Already, he says, he is gathering data from similar monitoring stations established on faults in central and southern California. Admittedly, Lindh says, "this project falls into the category of long-shot experiments. But anything you do in earthquake prediction has the potential to be a long shot. And this happens to be the most promising method of near-event earthquake prediction around."

■ *For more information, contact H. T. Tang, (415) 855-2012.*

Device Developed for Bird Protection

EPRI-sponsored researchers have developed a technology to help prevent birds from flying into structures that can injure or kill them. The device, which emits a pattern of radiofrequency signals that are imperceptible to human beings, has been tested successfully in the laboratory. Now the researchers are preparing to test it in the field.

The technology was conceived for use at wind farms. But according to EPRI's Earl Davis, who is managing the ongoing

research at the University of Pittsburgh, it has the potential to be useful in a variety of applications—for diverting birds away from airplane engines, tall buildings, and sites containing hazardous chemicals, for example. The technology could even be used to drive nuisance birds away from areas like sports stadiums and hotels.

"The historical approach to this kind of diversion has been to use lights and sounds that people can perceive," says Davis, "but these techniques are not necessarily the best way of communicating with animals." EPRI's technology emits a pattern of radio signals in a frequency already approved by the Federal Communications Commission for broadcasting. Since these signals cannot be detected by human ears, they can be used in areas where people are present.

The aim of EPRI's research is to successfully startle birds away from a given danger zone. In laboratory tests at the University of Pittsburgh, researchers have determined that pigeons perceive and recognize the radio signals. Complementary signals, such as ultraviolet light and sound, may be used to enhance the technique.

The next step is to test the device under controlled conditions on other bird species in the field. Commercialization would follow. In the meantime, EPRI has applied for a patent on the technology. The U.S. Air Force, which is plagued by the problem of birds flying into the engines of its aircraft, is among the groups that have already shown considerable interest in the device, Davis says. "This technology has the potential for great commercial value," he concludes.

■ *For more information, contact Earl Davis, (415) 855-2256.*

New Magnets Promise More-Efficient Motors

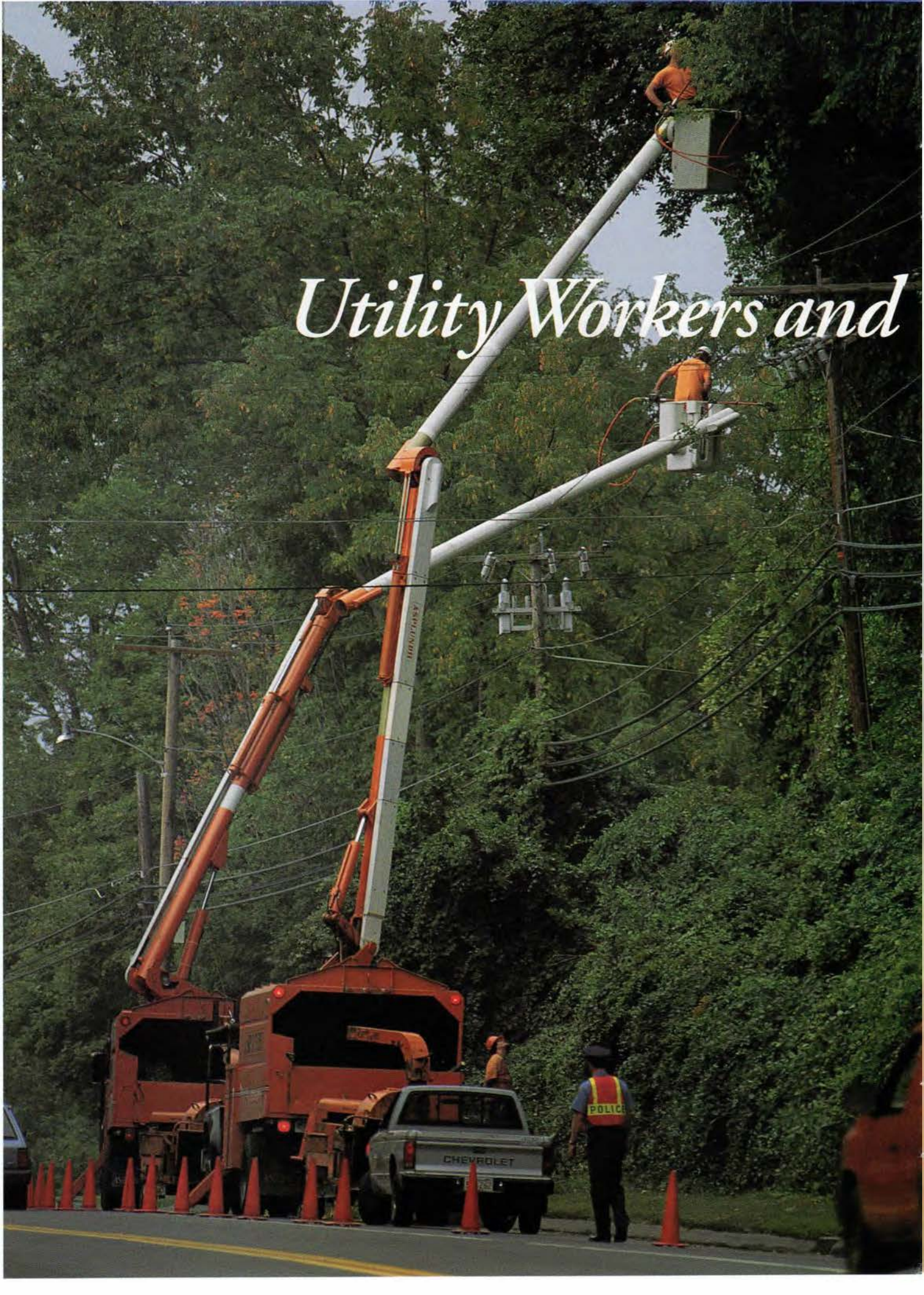
Large electric motors—those of 20 hp or more—consume more than one-third of the electricity generated in the United States, so even a small increase in their efficiency could provide significant energy savings. Most of these motors now use only electromagnets, which are relatively large. If permanent magnets were used, the size and weight of these motors could be reduced by about half, and their efficiency could be increased from the present average of about 88% to as much as 96%.

Most of today's permanent-magnet motors have fractional horsepower and typically use materials based on ferrites (mixed oxides of iron and barium or strontium). Much more powerful magnets—with more than five times the magnetic flux density of ferrites—can be made from alloys composed of rare-earth and transition metal elements. These RE-TM materials are commonly used in such small applications as earphones and computer disk drives, but their magnetic properties are unstable in situations where temperatures fluctuate widely, as in large motors.

Recently, EPRI's Strategic Development Group sponsored a scoping study by Daedalus Associates to explore opportunities to use advanced RE-TM materials for the benefit of the electric power industry. In particular, the Daedalus researchers looked for new materials with a higher Curie temperature—the temperature at which atomic-level randomization of molecular orientation makes permanent-magnet characteristics disappear. In addition to identifying promising candidate materials, the researchers concluded that new approaches—such as postconstruction magnetization—could overcome some of the difficulties previously encountered in trying to fabricate large motors with permanent magnets.

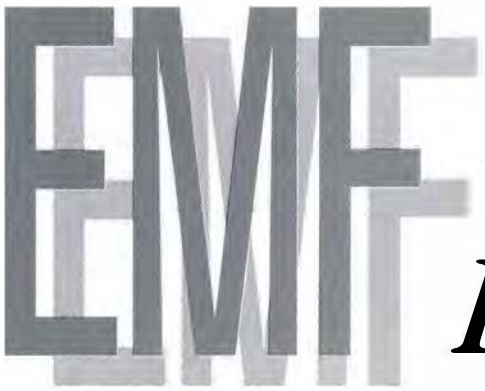
"We are currently considering further research, including the investigation of manganese-based materials and an economic analysis of their use in large motors," says John Stringer, EPRI's director of applied research. "It would be particularly beneficial to utilities if permanent magnets could be used to build more-efficient motors of 100 hp and up, because these are used mainly in power plants and consume about 10% of the power generated."

■ *For more information, contact John Stringer, (415) 855-2472.*



Utility Workers and

by Taylor Moore



Health Risks

THE STORY IN BRIEF *Previous studies suggesting an increased risk of leukemia and brain cancer among workers in electrical occupations generally involved small numbers of cases and had very limited information on magnetic field exposure and on exposures to other agents. Three large epidemiologic studies of electric utility workers that included extensive exposure measurements and were designed to test specific hypotheses about potential cancer risks have recently been completed. Their results, although inconsistent, have substantially enlarged the epidemiologic foundation for researchers probing the potential health risks of magnetic field exposure.*

Despite efforts by some of the world's leading epidemiologists and health researchers, the possible effect on human health from exposure to magnetic fields remains uncertain. Since the earliest suggestion of an apparent link with certain forms of cancer was reported 15 years ago, scientists supported by government and industry research programs in more than half a dozen countries have conducted increasingly refined and better-designed health studies that have probed for increased risk of disease from exposure to power system frequencies of alternating-current magnetic fields. Key populations studied have been children in typical residential environments—who spend most of their time at home and who are believed to be perhaps the group most vulnerable to possible risks—and adult workers in the so-called electrical occupations, who presumably have received higher exposures to magnetic fields than other populations.

So far, the results of the epidemiologic studies have been inconsistent. Many investigators have reported an association between increased risk of certain cancers and estimated exposure to magnetic fields; different studies have reported associations with different types of cancer, however, and the suggestions of increased risk are relatively weak when compared with some other causes of cancer, like cigarette smoking or exposure to certain toxic chemicals. Moreover, the association of risk with imputed exposure, particularly for childhood leukemia, has not been nearly so apparent when the epidemiologic data are analyzed by using actual exposure measurements.

Although important insights into the extent and nature of human exposure to magnetic fields and into the difficulties of epidemiologic research in this area have been gained, solid conclusions or definitive answers about possible health risks remain elusive. Beyond epidemiologic studies, laboratory research involving animals and cells is being conducted in several countries to investigate possible biological mechanisms by which power-frequency magnetic fields may interact with biological systems. Meanwhile, considerable electrical engineering research is being focused on evaluating options for limiting human exposure to magnetic fields.

Still, it is in the epidemiology of cancer incidence and mortality that some of the most extensive investigations for a link between magnetic field exposure and cancer have been centered in recent years. And it has been particularly among utility workers that epidemiologists have hoped to find the clearest evidence, or lack thereof, for increased health risks. The results of an important study taking this approach have recently been reported. This investigation, one of the largest epidemiologic studies ever conducted in this country, involved nearly 139,000 workers at five American utilities and was funded primarily by EPRI (with cofunding from the Empire State Electric Energy Research Corporation). With these results and recent results from other key studies, a substantially higher plane has been reached in the amount and quality of epidemiologic information about possible health risks from occupational exposure to magnetic fields, if not yet in the full understanding of the information's meaning.

Early studies raised possibility

Since 1981, more than 50 studies have examined the occurrence of cancer among workers exposed to electric and magnetic fields (EMF). Until recently, these studies focused on a loosely defined group of electrical occupations. In the late 1980s, a number of studies were initiated that looked at specific occupations or industries and specific diseases, such as leukemia and brain cancer. These studies include the five-company U.S. utility worker study, conducted for EPRI by a research team at the University of North Carolina (UNC) School of Public Health under the direction of epidemiologists David Savitz and Dana Loomis; an EPRI-sponsored study of telephone workers by Johns Hopkins University researchers; a study by Southern California Edison Company of its workers; a study of workers at three large electric utilities in Canada and France; and a study of workers in Sweden.

Many of the earlier studies were hypothesis-generating studies that examined a collection of occupations presumed to involve exposure to EMF. The results were inconsistent: some studies showed a small-to-moderate elevation in mortality risk from leukemia or brain cancer among electrical workers; others showed no effect or even lower risk. None involved the measurement of exposure to magnetic fields or even a close look at job history; many were based solely on information from death certificates. The results served mainly to raise the possibility that a relationship between job exposure to EMF and disease might exist.

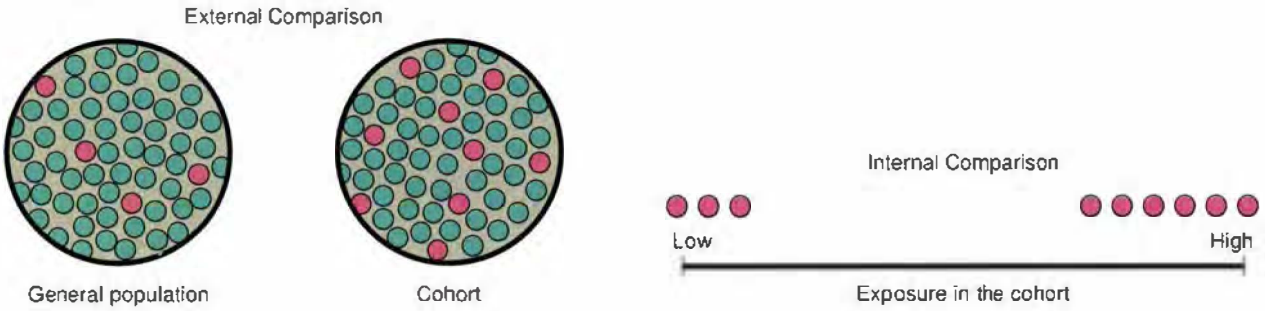
Later studies of occupational EMF exposure and cancer focused mainly on brain cancer and leukemia, although a few looked at other cancers, such as male breast cancer and malignant melanoma (a severe form of skin cancer). These studies shared some of the limitations of the earlier studies: a nonspecific definition of electrical occupations, no measurement of EMF exposure, limited information on work history, and relatively few cases of disease.

Several analyses combining the results of various studies have been conducted. One published in 1988 found relative risks of 1.18 for all types of leukemia combined and 1.46 for acute myeloid leukemia, the type most common in adults. (Relative risk is the ratio of risk among exposed subjects to the risk among the unexposed. A value of 1.0 indicates no risk.) At least 12 case-control studies of brain cancer and occupational EMF exposure have been done. Several showed a small excess risk (a relative risk of 1.5 to 2.0) for all electrical occupations combined and larger risks (above 5.0) for some subgroups. The occupational groups showing excess risk, however, differed from study to study. And since brain cancer is rare, the number of subjects in a specific occupation in any one study was small.

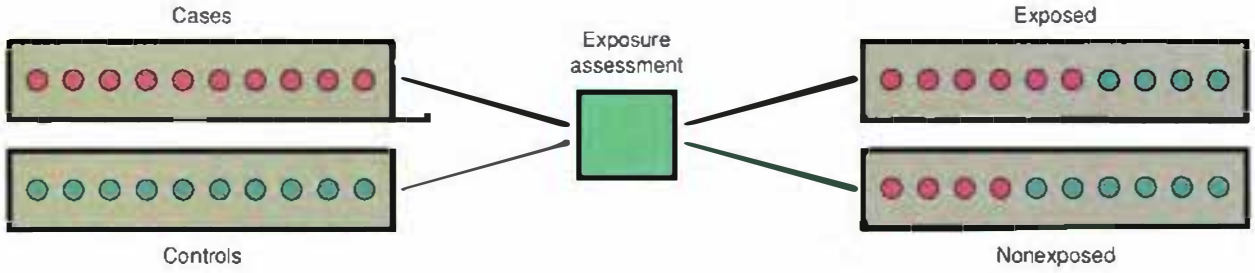
Indeed, part of the difficulty of epidemiologic studies of EMF is that both leukemia and brain cancer are relatively rare diseases. Leukemia in its several forms occurs at a rate of about 10 cases per 100,000 people a year, or about 28,600 new cases annually in the United States. Rates for all types of leukemia have changed little over the past two decades. Brain and central nervous system cancers are rarer, occurring at a rate of about 8 per 100,000 people a year.

CONTRASTING TYPES OF EPIDEMIOLOGIC STUDIES

Hypothesis-generating studies that used death certificate information to examine the occurrence of disease in populations first raised the possibility of a link between certain forms of cancer and presumed occupational exposure to magnetic fields. More recently, two types of analytical studies—cohort and case-control studies—have been conducted to test hypotheses regarding specific cancers and occupational exposure to magnetic fields. These studies involve the collection of detailed data on exposure, disease, and other factors. Both types may be used to examine the relationship of exposure either to the occurrence of disease or to disease mortality.



Cohort studies identify and select groups (cohorts) of individuals for study typically on the basis of some exposure of interest—for example, exposure to magnetic fields. Investigators determine the disease incidence or mortality patterns within the cohort. They then make comparisons of incidence or mortality rates between the cohort and the general population or between subgroups with different levels of exposure within the cohort.



Case-control studies start by identifying individuals who have the disease of interest (cases) and individuals without the disease (controls). Investigators then compare the previous exposure experience of cases with that of controls. Faster and less costly than some cohort studies, case-control studies can achieve adequate statistical power with smaller sample sizes. They can be more prone to bias, however. Nested case-control studies combine some features of both cohort and case-control studies.

For brain cancer, both the rate of incidence and the rate of mortality have been increasing slightly since 1973; however, that is thought to be at least partly the result of improved detection and diagnosis using noninvasive imaging techniques, such as CAT scans and magnetic resonance imaging.

Environmental, occupational, and genetic factors have all been associated with one or more types of leukemia. Exposure risk factors include the organic solvent benzene and ionizing radiation, such as X-rays. (Power-frequency magnetic fields, in contrast to ionizing radiation, are much lower in frequency and are not believed to have DNA-damaging potential.) Although there are no clearly recognized risk factors for brain cancer, occupational exposures to ionizing radiation, organic solvents, and pesticides have been linked to the disease. But the causes of leukemia and brain cancer are not well understood, and, taken together, the currently known or suspected risk factors are likely to account for only a small proportion of cases, EPRI researchers say.

COMPARISON OF THREE STUDIES OF UTILITY WORKERS

Three recent occupational EMF studies incorporate significant improvements over earlier studies. Possibly important differences among the recent studies include what size cohort they used, whether they examined the incidence of disease or only deaths from disease, whether magnetic field exposure measurements were random, and whether the potential for confounding exposures was taken into account.

	Sahl et al. 1993	Thériault et al. 1994	Savitz et al. 1995
Utility	Southern California Edison	Electricité de France Ontario Hydro Hydro-Québec	Carolina Power & Light Pacific Gas and Electric PECO Energy Tennessee Valley Authority Virginia Power
Design			
Cohort size	36,221	170,000 (EdF) 31,543 (OH) 21,749 (HQ)	138,905
Follow-up period	1960–1988	1970–1989	1950–1988
Type of study	Nested case-control	Nested case-control	Cohort
Outcome			
Type	Mortality	Incidence	Mortality
Main focus	Leukemia Brain cancer Lymphoma	Leukemia Brain cancer Malignant melanoma	Leukemia Brain cancer
Exposure Assessment			
Sampling	Convenience	Convenience	Random
Instrument	EMDEX	Positron	AMEX-3D
Number of measurements	776	2066	2842
Median exposure (milligauss × yr)	35	22 (EdF) 49 (OH) 63 (HQ)	52
Adjustment for other exposures	No	Yes	Yes

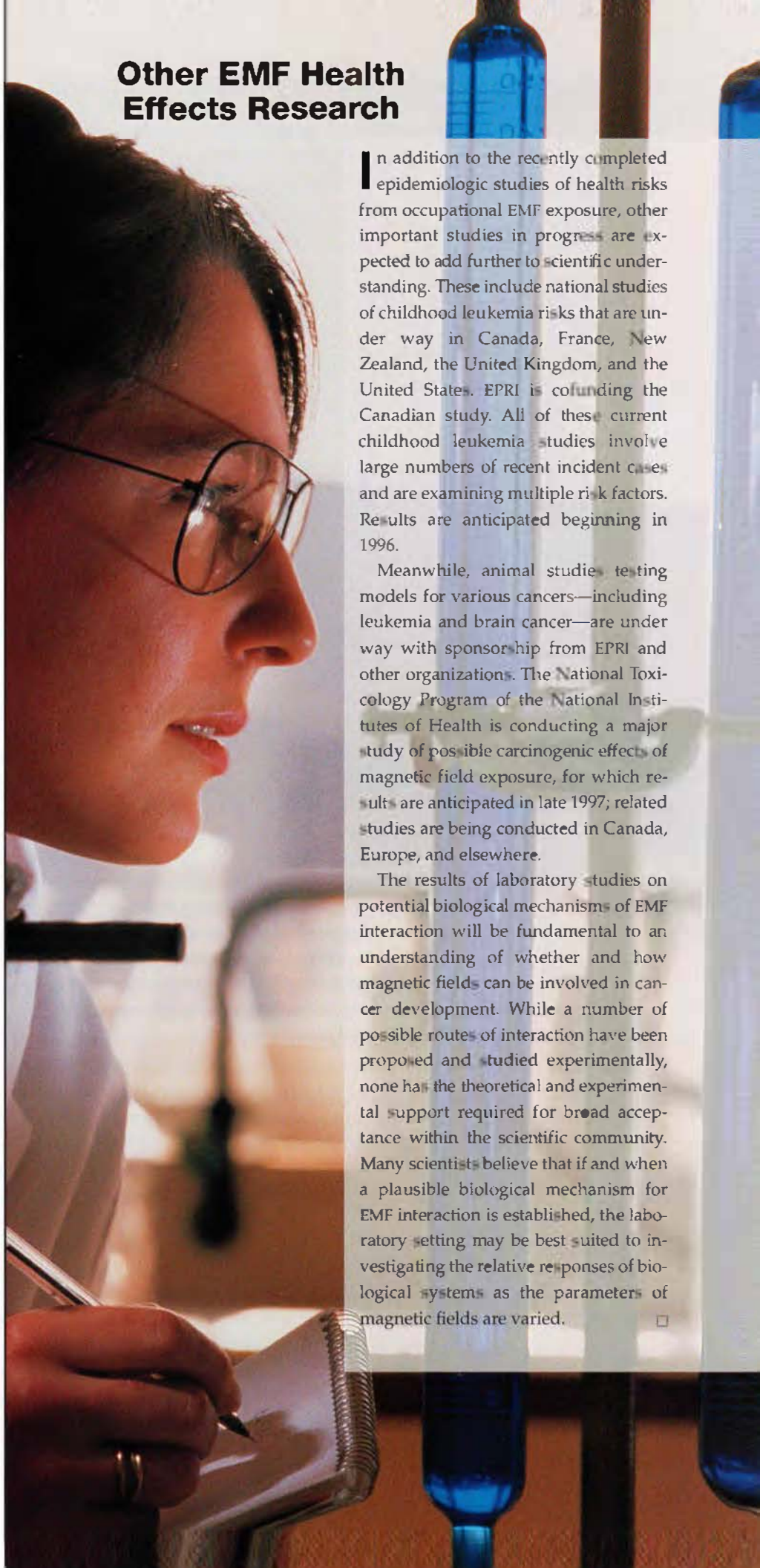
More-recent studies

In 1992, researchers from Johns Hopkins University published the results of an EPRI-sponsored case-control study of leukemia among telephone linemen, for whom an important source of EMF exposure is the electric power distribution system, since telephone and power lines are often close together. This was the first occupational study of EMF to look at exposures and risks in a large population, and it used measurements of on-the-job exposures and telephone company records of job histories. Exposure estimates for four categories of lineman jobs and one for all other telephone company jobs were based on 238 full-shift measurements of EMF exposure using an EPRI-developed recording exposure meter—the EMDEX.

Overall, the study did not find clear evidence of an excess risk of leukemia mortality among telephone company linemen. Those who were exposed to high levels of magnetic fields of rapidly varying intensity, however, had excess risks—in the range of 1.5 to 6 times higher than the least-exposed workers. Risks among these workers increased with increasing exposure. Because the actual number of subjects for whom detailed work histories were available was small, however, the estimate of risk was imprecise and not statistically significant and the researchers concluded that the observed differences may have been due to chance. (See sidebar, p. 16.) Moreover, many of the analyses made in the study were considered exploratory and were not based on a hypothesis specified beforehand.

Meanwhile, in separate studies published in 1993, researchers at Sweden's National Institute of Occupational Health and in Denmark used national cancer registry and census data in population-based studies of workers. (U.S. cancer incidence data, in contrast, are not collected nationally.)

The Swedish case-control study examined all cases of leukemia and brain cancer over a 4-year period among adult men in a region of central Sweden. Questionnaires and measurements of magnetic fields where subjects worked formed the basis for exposure assessment. Workers were queried about potential confounders, such as exposure to chemical or other agents, that could



G. Tompkinson/Science Source

Other EMF Health Effects Research

In addition to the recently completed epidemiologic studies of health risks from occupational EMF exposure, other important studies in progress are expected to add further to scientific understanding. These include national studies of childhood leukemia risks that are under way in Canada, France, New Zealand, the United Kingdom, and the United States. EPRI is cofunding the Canadian study. All of these current childhood leukemia studies involve large numbers of recent incident cases and are examining multiple risk factors. Results are anticipated beginning in 1996.

Meanwhile, animal studies testing models for various cancers—including leukemia and brain cancer—are under way with sponsorship from EPRI and other organizations. The National Toxicology Program of the National Institutes of Health is conducting a major study of possible carcinogenic effects of magnetic field exposure, for which results are anticipated in late 1997; related studies are being conducted in Canada, Europe, and elsewhere.

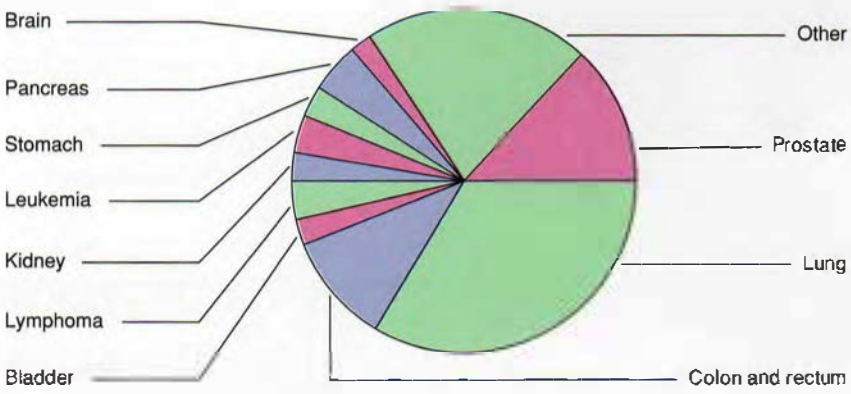
The results of laboratory studies on potential biological mechanisms of EMF interaction will be fundamental to an understanding of whether and how magnetic fields can be involved in cancer development. While a number of possible routes of interaction have been proposed and studied experimentally, none has the theoretical and experimental support required for broad acceptance within the scientific community. Many scientists believe that if and when a plausible biological mechanism for EMF interaction is established, the laboratory setting may be best suited to investigating the relative responses of biological systems as the parameters of magnetic fields are varied. □

SELECTED CAUSES OF DEATH IN THE U.S. UTILITY WORKERS COHORT
(Cohort Size: 138,905)

	Observed Deaths	Expected Deaths
All causes	20,773	26,779.5
All cancers	4,833	5,616.1
Selected cancers		
Lung	1,692	1,859.5
Breast	6	7.5
Brain and central nervous system	151	158.4
Lymphatic and hematopoietic	439	532.4
Leukemia	164	217.0
Heart disease	7,768	10,209.1
Respiratory disease	1,178	1,716.8
Transportation accidents	810	1,105.8
Accidental falls	141	190.8
Suicide	536	661.3
Homicide	175	418.1

CAUSES OF DEATH FROM CANCER IN THE U.S. MALE POPULATION Leukemia and brain cancer deaths are rare in the overall picture of cancer in the general population. The UNC mortality study of workers at five U.S. electric utilities found fewer deaths from all causes, from all cancers combined, and from leukemia and brain cancer specifically than would be expected in the general male population. This is attributed to the tendency for employed people to be healthier than the general population.

Cancer Deaths: General Male Population
(1994 Estimates)



either create a spurious association or mask a real one. Jobs held the longest during the preceding 10 years were then targeted for EMF measurements by subjects or surrogates wearing personal exposure meters.

Swedish researchers reported that EMF exposure in the job held longest in the 10 years before diagnosis was associated with chronic lymphoid leukemia (odds ratio of 3.0 to 4.0) but not with the other common form in adults, acute myeloid leukemia. (Odds ratios are calculated in case-control studies as estimates of the relative risk of disease associated with exposure.) Brain cancer risk was weakly associated with mean exposure in the job held longest. But because the study looked at many jobs and industries, it yielded little information on risks among electric utility workers per se.

Major studies of electric utility workers

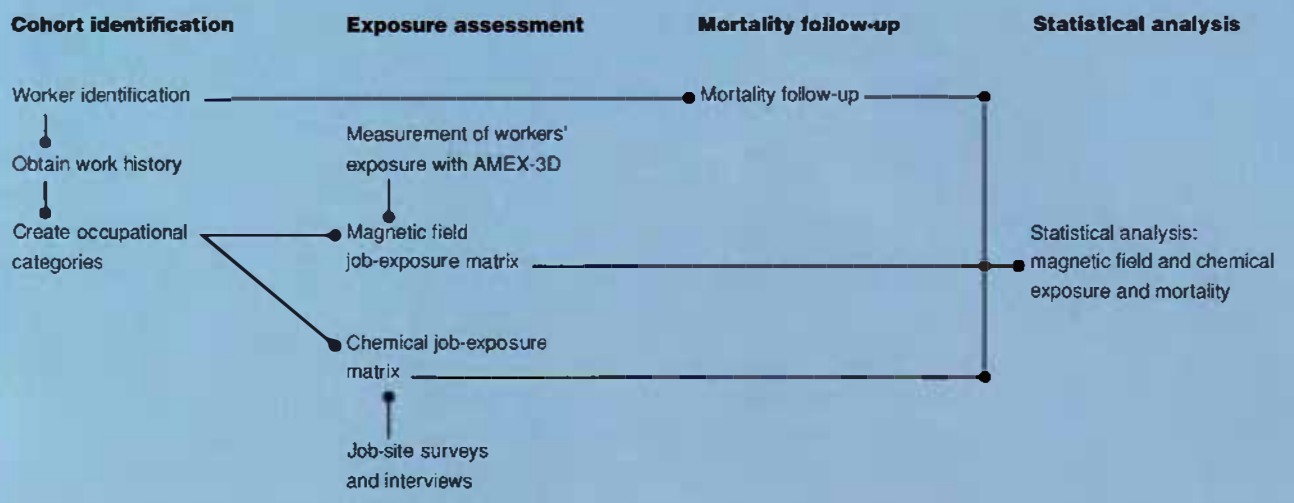
Three recent studies looked directly at electric utility workers and were specifically designed to resolve much of the uncertainty that plagued earlier, more limited projects. Because of this, the results of these studies are the focus of much of the attention of EMF health researchers today. The principal results of the EPRI-funded, five-company study of U.S. workers by UNC researchers were published in January in the peer-reviewed *American Journal of Epidemiology*.

The same journal last year published the results of a second large study, begun at around the same time in 1988 and based on 223,000 utility workers in Canada and France. That study was a cooperative effort of research groups led by Gilles Thériault of Montreal's McGill University, Anthony Miller of the University of Toronto, and Marcel Goldberg of France's National Institute of Health and Medical Research. The results of a third study, which evaluated cancer risks among 36,221 Southern California Edison (SCE) workers over a 28-year span, were published in the spring of 1993 in *Epidemiology*.

Each of these studies had strengths and weaknesses that limit the interpretation of their results. But all were designed to yield a more credible assessment of magnetic field exposures and to test hypotheses specified beforehand.

HOW THE UNC STUDY WAS DONE

Here are the key steps followed by researchers at the University of North Carolina School of Public Health in examining mortality patterns and risks for leukemia and brain cancer among workers at five U.S. utilities.



All males who had worked at any of the utilities full-time for at least six months between January 1, 1950, and December 31, 1986, were eligible and were identified from company personnel records. Records were used to assemble complete work histories. Jobs were grouped into 28 occupational categories.

From the cohort, over 4000 workers were randomly selected to wear the AMEX-3D device to obtain full-shift exposure measurements. More measurements were made in larger companies and in jobs with potential for higher exposure. Time-weighted average exposure data from the measurements were used to derive magnetic field exposure estimates for the utility occupational categories; these estimates were, in turn, grouped into five categories of exposure distribution. Potential exposures to PCBs and solvents were also examined.

State death certificate data and a comprehensive national roster were used for mortality follow-up and classification of the specific causes of death among the cohort members. Driver's license renewal, credit card application, and other records were used to help identify men who were still alive at the end of the study period.

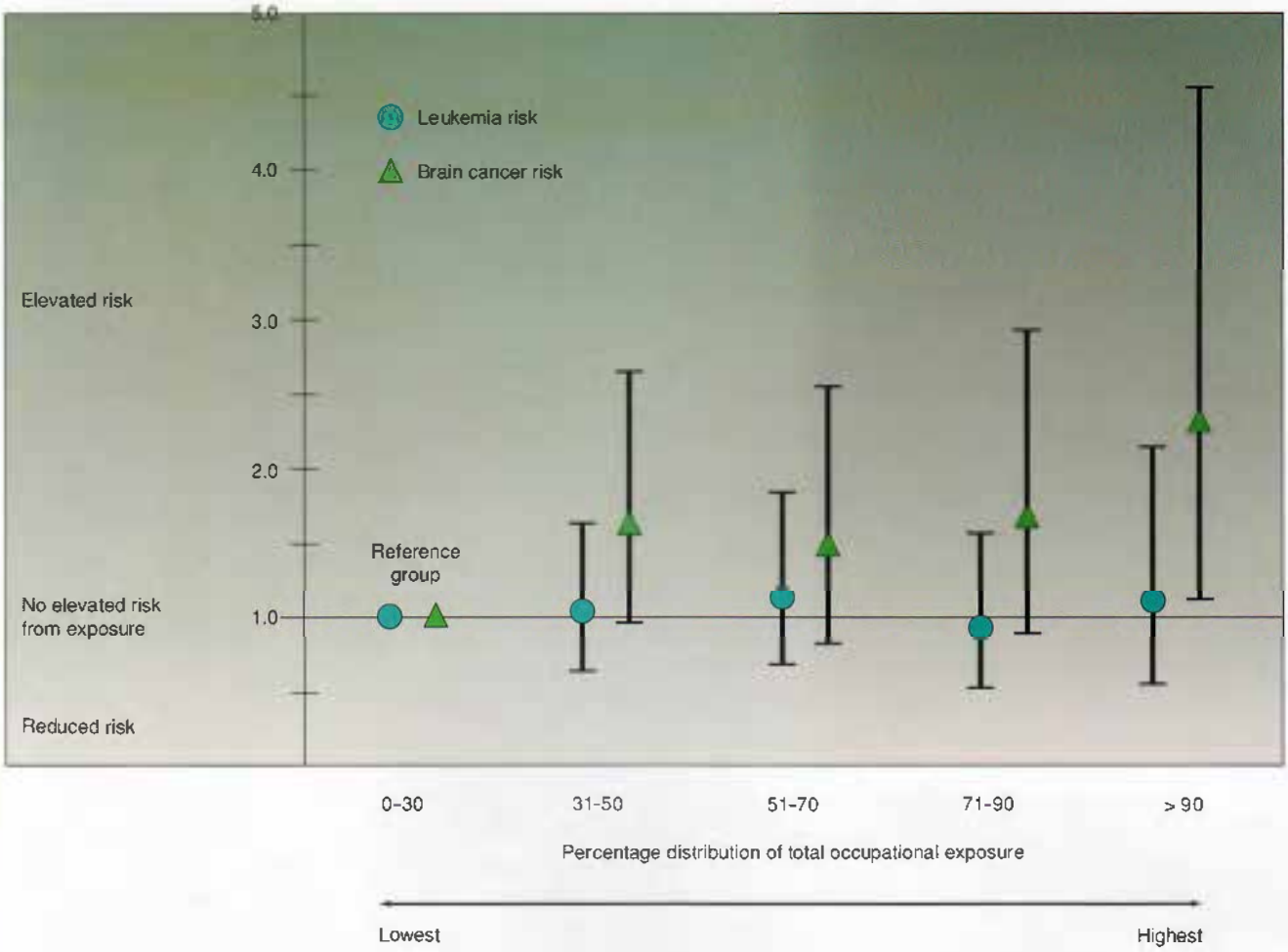
Researchers combined the data from the cohort exposure assessment and the mortality follow-up to perform several types of analysis. Mortality rates for all deaths, for specific cancer types, and for other causes in the cohort were compared with those in the general population. Within the cohort, rates were contrasted on the basis of cumulative magnetic field exposure and duration of employment in some jobs. For all analyses, mortality rates were adjusted for age, social class, and other potential confounding factors.

The SCE study combined cohort and nested case-control components to evaluate the possible relation of mortality from leukemia, lymphoma, and brain cancer with occupational exposure to magnetic fields. The cohort consisted of employees of SCE who had worked for at least a year between 1960 and 1988.

Exposure was estimated in several ways and was based on a reconstruction of each worker's job history. In the cohort study, exposure status was categorized on the basis of job title. The case-control study used exposure scores based either on time spent in electrical craft occupations or on an integrated magnetic field exposure history. Exposure data came from volunteers in relevant jobs at SCE who wore EMDEX recording meters.

The researchers reported that electricians had the highest exposures (mean = 30.1 milligauss, median = 3.7 milligauss), followed by machinists. Plant operators, shop technicians, linemen and cable splicers, and welders were also among the high-exposure workers.

Among the 36,221 workers in the cohort, known deaths numbered 3125, including 44 from leukemia, 67 from lymphoma, and 32 from brain cancer. For electrical workers considered as a group, the mortality risks from leukemia, brain cancer, and all cancers combined were similar to those for the comparison groups. Most of the risk estimates were close to 1.0, except for lymphoma, for which a slightly elevated—but not statistically significant—risk was seen in the cohort analysis. In general, the results were similar regardless of study de-



UNC RESULTS ON LEUKEMIA AND BRAIN CANCER RISK **In this graph, the risks of leukemia and brain cancer (with associated 95% confidence intervals) for the four higher exposure-distribution categories in the UNC utility workers study are compared with the risks for the category of workers who received the least exposure (the reference group), for which the risk is set at 1. The results indicate no elevation of risk for leukemia among the exposed groups compared with the reference group. There is a trend of elevated risk for brain cancer with increasing cumulative occupational exposure, however.**

sign or reference group.

The results of analyses for specific job titles varied somewhat. In the cohort analysis, slightly elevated mortality risks (relative ratios of 1.25 to 1.30) from leukemia and brain cancer were observed for electricians, but the corresponding estimates in the case-control analysis were substantially lower. Because of the small numbers of cases and only slightly increased odds ratios (below 2.0), the results were not statistically significant. There was no evidence that risk increased with length of employment. In all analyses that used exposure scores (including those of latency and exposure windows), odds ratios were close to 1.0.

Improvements in the SCE study over previous studies that should have helped to minimize bias and enhance the validity of the results included thorough enumeration of the cohort, detailed information on occupational history, magnetic field measurements, and sophisticated data analysis. EPRI researchers say that because the SCE study is similar in important respects to the five-company UNC study, their results may be the most comparable. Limiting the precision of the SCE study's results are its relatively small numbers of cancer cases and the lack of data on confounding factors, such as exposure to chemicals.

In contrast with the SCE study, the Canada-France study explicitly analyzed worker exposure to potential confounders. It also derived estimates of magnetic field exposure from an even more extensive measurement survey. The three groups conducting this study examined cancer risk in relation to EMF exposure among men employed by Hydro-Québec, Ontario Hydro, and Electricité de France. Men who had

worked for at least one year were identified at each of the utilities, with the Canadian cohorts including retired as well as active workers.

The Canada-France study used a nested case-control design, combining features of cohort and case-control studies. Researchers compared the EMF exposures of cases with those of controls in each group. The epidemiologic endpoints specified at the start of the study were the incidence of—not deaths from—all cancers combined, leukemia, brain cancer, and malignant melanoma.

Estimates of EMF exposure were obtained by combining the job history of each worker with information on EMF exposure from each job. Job-specific estimates were based on extensive measurements among employees of the three companies. In all, 2066 workers wore for one week a commercial EMF exposure meter originally developed by Hydro-Québec that measures magnetic fields, electric fields, and high-frequency electromagnetic transients.

Potential confounders that were specifically addressed in the Canada-France study included smoking, ionizing radiation, chemical agents, and sunlight. Data on smoking were available only from the medical histories of subjects from Hydro Québec, however. Occupational hygienists at each of the companies developed estimates of exposure to chemicals and sunlight for each job category. In an approach similar to that used to estimate EMF exposure (but without the measurement component), each subject's job history was combined with the estimated exposure to obtain a cumulative exposure estimate for each chemical agent. Statistical methods were used to estimate the effects of the primary exposure (EMF) on disease risk while adjusting for possible effects of the confounding factors.

Half of the workers in the Canada-France study had cumulative exposures of 31 milligauss-years or less. They served as the baseline against which researchers estimated risks for the subjects with above-median cumulative exposures and for the 10% of workers with the highest cumulative exposures.

The researchers found one type of leukemia—acute nonlymphoid leukemia (ANLL)—to be associated with cumulative magnetic field exposure. In a comparison with the baseline group, ANLL risk was found to be 2.4 times higher among the half of workers with greater exposures. When only acute myeloid leukemia—a subset of ANLL—was considered, the risk among the half of workers with the higher exposures increased to about 3.1, although no exposure response relationship was found in a more detailed analysis.

In addition, an elevated risk for one type of brain cancer, astrocytoma, was found in the 10% of workers with the highest cumulative exposures. Researchers said that they suspect the result may be an artifact of the statistical method used to adjust for socioeconomic status, because it diminished sharply without this adjustment. The results of the Canada-France study did not confirm earlier suggestions of an increased risk of malignant melanoma or male breast cancer.

"Despite the attempts made in this study to achieve adequate [statistical] power, definitive evidence of an association between exposure to magnetic fields and leukemia and brain cancer has not been obtained," the Canadian and French researchers concluded in their peer-reviewed publication of results. "One of the main hypotheses tested was the association between magnetic fields and acute nonlymphoid leukemia (acute myeloid leukemia) that has been reported in several other studies. Considering that among all the cancers analyzed in our study this is the one for which a statistically significant association was found, we believe our results speak for an association between exposure to magnetic fields and at least one type of leukemia."

UNC's utility worker study for EPRI

Because it also incorporated the methodological improvements applied in the SCE and Canada-France studies and because of its large cohort size, the five-company UNC study substantially deepened the epidemiologic understanding of the possible risks of occupational EMF exposure. The cohort included all men who had been full-time permanent employees of one of the utilities for at least six months between 1950 and 1986. The utilities that participated in the study were Carolina Power & Light Company, Pacific Gas and Electric Company, PECO Energy Company, the Tennessee Valley Authority, and Virginia Power.

The UNC researchers assembled a work history for each man, listing length of time in each job held with a utility. These histories became part of the basis for estimating each worker's cumulative magnetic field exposure. The other key element was 2842 full-shift measurements of exposure to magnetic fields for a random sample of workers in 28 utility occupational categories. The workers wore a lightweight EPRI-developed device called the AMEX-3D that measures the time-weighted average magnetic field. Information from the AMEX-3D measurements was linked with job histories to estimate cumulative occupational exposure for the study subjects. In general, worker exposures were comparable to those reported in the Canada-France study.

To evaluate possible confounders, UNC industrial hygienists assessed worker exposure to a number of other agents (including solvents and PCBs), surveyed facilities and work practices, and consulted with longtime employees at the participating utilities about confounder exposure potentials in each of the 28 job categories. The statistical analyses of risk included adjustment for potential confounding by these and other factors, including age and social class.

Of the 138,905 individuals in the study, 76,934 were no longer employed by the companies and had to be traced. Vital statistics were determined by various means for more than 99% of the study subjects. By the end of the period being studied, deaths among the cohort totaled 20,773. The UNC researchers first compared the mortality patterns of the study group with those of the general population. They then compared the mortality rates of the more exposed subgroups of the cohort with the rates of the least-exposed subgroup (defined as the lowest 30%).

The overall rate of death in the five-company worker cohort was 23% below the expected rate for the U.S. male population—a result attributed to the tendency, also seen in other occupational studies, for em-

ployed people to be healthier than the general population. Overall mortality was also low compared with the total male population for all cancers combined and for most specific types of cancer. The standardized mortality ratio (observed deaths from a given cause divided by the number expected among men of the same age and race in the population as a whole) for leukemia was 0.76 (at a 95% confidence interval of 0.64–0.88), while that for brain cancer was 0.95 (95% CI of 0.81–1.12).

When the risk of brain cancer was examined by comparing worker groups categorized by percentiles of the exposure distribution, the relative risk for the three middle categories (compared with the least-exposed group) was about 1.5, and for the highest-exposure category, 2.3 (95% CI of 1.15–4.56). Similar analyses for all leukemias showed no association of risk with increased exposure.

Examination of risk by duration of employment for all exposed jobs combined and for linemen, electricians, and power plant operators—categories with sufficiently large numbers of workers with high potential for exposure—did not identify consistent patterns of risk, although there was an elevated leukemia risk for electricians.

The Significance of Statistical Significance

Statistical significance is often confused with practical or biological significance and, as such, is often misused. One way to assess the statistical significance of epidemiologic results is through a confidence interval (CI)—an interval calculated to contain the true, but unknown, value of the risk with a specified probability (usually 95%). The larger the CI, the less precise the risk estimate. Conversely, the narrower the CI, the greater the estimate's precision. But importantly, if the CI includes 1.0, it means that the possibility that there is no effect cannot be excluded and that observed differences in risk could have been the product of chance. So risk ratios with a 95% CI that includes 1.0 are said to be not statistically significant, while those with a CI whose lower limit is above 1.0 are statistically significant.

While statistical significance is related to the strength of an association (e.g., large risks are more likely to be significant), it also depends on such factors as sample size, variability of the exposure of interest, and how common that exposure is. So a risk of 2.0 might be statistically significant in a large study but not in a smaller one. In another study of a given size, a risk of 5.0 might be statistically significant, but a risk of 3.0 might not be.

The greatly elevated (10 to 20 times higher) risk of lung cancer among cigarette smokers compared with nonsmokers makes it less likely that some other variable, or confounder, is actually responsible for the association. On the other hand, it is harder to rule out the possibility that a low relative risk may result from some problem in the study design or from factors other than those under examination. When elevated risks have been found for the cancers most frequently examined in EMF studies (leukemia and brain cancer), they are mostly below 3.0. That, by itself, doesn't mean that the association isn't real, but it does make the association more difficult to study. □

Bruce Rowell/Masterfile Corp.

The UNC researchers concluded that "in contrast to other studies, these data do not support an association between occupational magnetic field exposure and leukemia but do suggest a link to brain cancer."

In a summary prepared for release concurrent with the publication of the study results, Savitz and Loomis elaborated on their interpretation. "The large size of the study, random selection of a large number of workers for magnetic field measurements, and examination of chemical exposures are clear strengths relative to most previous [studies]. Although the most recent studies had found evidence that magnetic fields were related to leukemia, we did not. Some suggestions of an association were found, but overall we did not find nearly the degree of support seen in a number of other studies, including the Canada-France study of electric utility workers. The positive association between magnetic fields and brain cancer that we saw was stronger than had been seen in previous studies of electric utility workers, again compared to both the Southern California Edison study and the Canada-France study."

The UNC researchers continued, "It is disappointing that our results do not provide a clearer picture when combined with the previous studies of electrical workers and particularly electric utility workers." They said that various decisions made in conducting the study and in analyzing the data could have led to different results but that this was not likely. For example, the UNC study used a random sample of workers to measure EMF exposure, while other studies did not randomly select workers for exposure measurements. In addition, the UNC study of mortality risk relied on death certificates, while researchers in the Canada-France study examined the incidence of cancer.

"Classification of EMF exposure remains the biggest challenge in epidemiologic studies," concluded the UNC researchers. "If some more subtle aspect of magnetic fields is truly related to leukemia or brain cancer, then we may have captured it more (or less) accurately than was done in other studies, and what appear to be comparable EMF exposures really are not. To advance our understanding, rather than more studies of the type just completed, we need to follow up on opportunities to measure exposure more accurately or develop and test more refined hypotheses about the biologically relevant aspect of exposure potentially related to cancer."

Summarizing his perspective on the UNC study results, Savitz says, "If the question is, does it seem more likely after our study that [magnetic field exposures] cause cancer than it did before our study? my answer would be that it seems slightly more likely, and I mean slightly. Our study adds some evidence that is clearly positive for brain cancer, and yet for leukemia, where the [earlier] results have been strongest, I think it adds important negative evidence. I don't think that should be ignored—we shouldn't look only at the brain cancer finding."

Savitz adds: "It would be much easier to give a one-sentence answer if that is what the results provided, but it's really inherent in the nature of research that you develop the methods and conduct the study with care and objectivity and the results come as they will. In this instance, at least at this time, there are some rather mysterious discrepancies among the major studies of the recent past."

EPRI perspective

Stan Sussman, target manager for EMF studies in EPRI's Strategic Development Group, comments: "UNC's large and comprehensive study of U.S. utility workers provides substantial new data on occupational exposures in the utility industry and adds important new information to the consideration of an association between occupational EMF exposure and cancer. But considered in the context of the other utility worker studies and the overall body of EMF research results, the most recent study of utility workers, despite many improvements, unfortunately has not clarified the relationship between EMF exposure and cancer. The inconsistencies in results among studies underscore our limited understanding of the risks of exposure to EMF among utility workers and suggest the need for further analyses and additional studies."

According to Leeka Kheifets, the EPRI project manager for the UNC study, "The three recent studies of utility workers have involved larger numbers than before, better assessments of exposure, and more-rigorous study designs. Taken as a group, the indications of risk in the recent studies remain relatively weak, even as the studies have been made more rigorous." She goes on, "Unfortunately, the detailed results of these recent studies are not consistent with each other, and that is probably frustrating to utility workers and scientists alike. But the studies amassed an enormous amount of very high quality data that need to be fully explored."

EPRI plans to compare the methodologies and results of the three studies to investigate the reasons for differences in the results and also plans to pursue other comparative analyses. The studies' focus on utility workers and their use of state-of-the-art exposure assessment are thought to offer a unique opportunity to better understand both exposure environments and potential risks in the industry. Explains Kheifets: "We are planning to bring all the researchers together and have them examine their data in more detail so that, we hope, a clearer picture will emerge and we will know where to go from there." ■

Further reading

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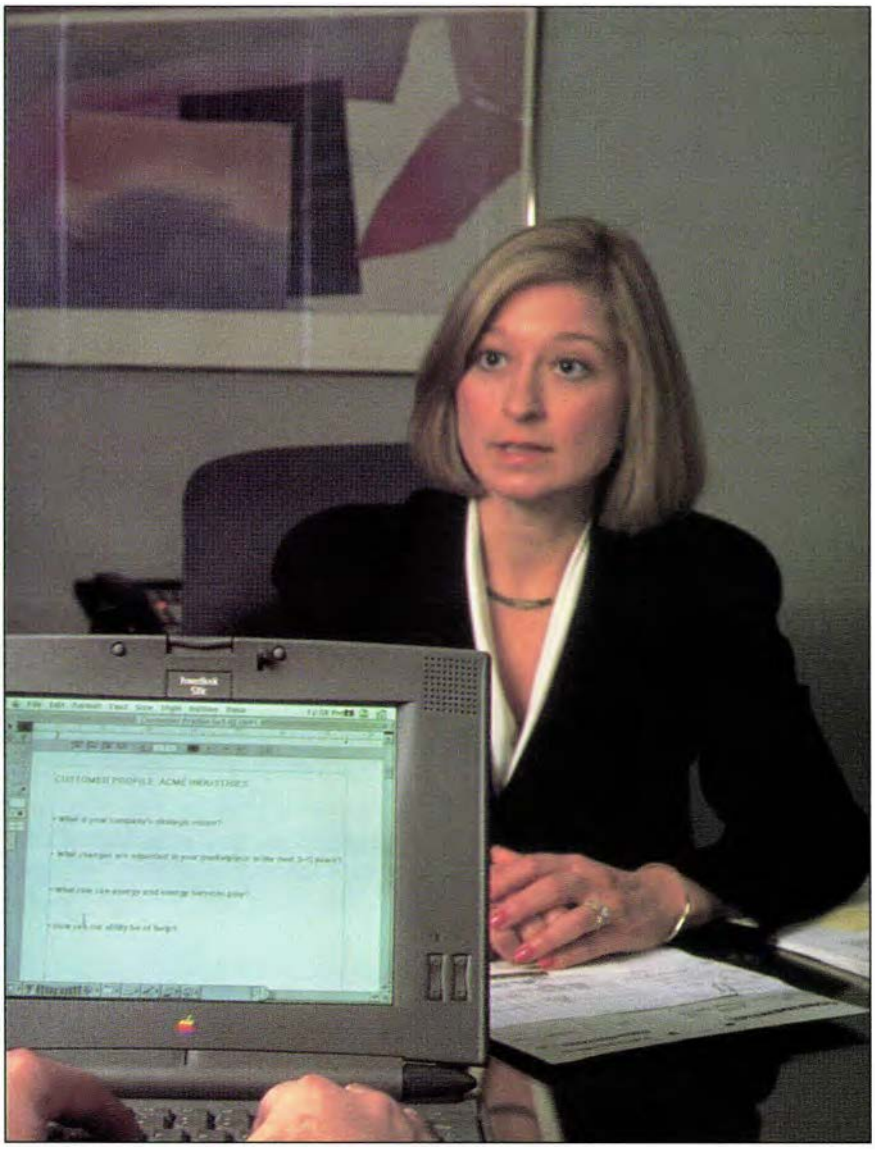
Background information for this article was provided by Leeka Kheifets and Stan Sussman of the Strategic Development Group's Environment & Health Business Unit.

Customer Value Deployment: Turning Information Into Action



by Peggy Waldman

THE STORY IN BRIEF Gearing up for increasing competition, electric utilities are spending millions of dollars on research to understand their customers. Yet knowing customer needs isn't enough. Companies must translate market intelligence into products and services that build customer loyalty and satisfaction, while compressing product development time and reducing costs. To those ends, some utilities are turning to a process that helped American automakers meet foreign competitors head on.

In August 1992, when PSI Energy wanted to encourage small businesses to install energy-efficient lighting, Jerry Brandom and his colleagues at the Indiana-based utility decided to try something different. According to Brandom, PSI's manager for market planning at the time, the utility's program design practices were already fairly strong. Still, he felt that those practices could be improved.

"We wanted to be certain we didn't waste time and spin our wheels by adding programs that didn't quite meet customer needs," Brandom says. Besides, he had learned something about a technique called quality function deployment, or QFD. First employed in the manufacturing sector but ultimately just as widely used in service industries, QFD—Brandom heard—was supposed to significantly slash the time and costs involved in bringing a new product to market. He called EPRI to find out more.

As it turned out, Thom Henneberger, EPRI's manager for product development and marketing, was already working to adapt QFD to the utility industry. Together with Henneberger and other EPRI experts, Brandom and his colleagues at PSI used EPRI's modified version of QFD, called customer value deployment (CVD), to establish a new lighting program.

Today Brandom reports that, despite its complexity, the program had one of the smoothest startups of any PSI marketing effort to date and has been among the most cost-effective PSI programs of its kind. All of this, plus a record-high customer satisfaction rate—well above 90%. "We met or exceeded all goals, including a target of reducing demand by 9.7 MW by 1995," Brandom says. Indeed this demand reduction goal, which was set for June 30, 1995, was reached by late January this year. Brandom estimates that using CVD saved PSI over $1 million in two years through reduced incentive costs, lower implementation costs, and the elimination of the need for program pretesting.

What started as an isolated experiment at PSI has grown into a way of doing business. "CVD is now our standard practice," Brandom says. "We've used the process to design virtually every program since we first tried it—from residential water-heating programs to customized industrial energy audit programs. We've even used it to redesign existing programs." In fact, about the time that PSI Energy merged with Cincinnati Gas & Electric Company last fall (the two entities remain separate operating companies under a new holding company, CINergy), Brandom and his colleagues assisted EPRI in a CVD training session for PSI and CG&E employees.

What is CVD?

PSI is in the vanguard of U.S. electric utilities turning to CVD as a way to speed up product cycles, reduce costs, and improve customer service. Naturally, since the process was inspired by the QFD concept, it bears strong similarities to its predecessor. QFD grew out of the quality movement—a movement, based on customer focus and continuous improvement, that revolutionized corporate America in the 1980s.

First implemented at Mitsubishi's shipyards in Kobe, Japan, more than 20 years ago, QFD made its way into the United States via Ford and Xerox in the mid-1980s. By 1991, according to one estimate, more than 100 companies—including service and manufacturing firms—were using some form of QFD. That the business world so readily latched onto QFD is no surprise. Companies that rely on the process have experienced reductions of 40% in design time and 60% in design cost. U.S. automobile manufacturers report that the process reduced auto design time from seven to three and a half years.

The basis of QFD, and hence CVD, is simply active listening to customer needs—something that just about every company recognizes is important today. Customer needs are addressed not only in the beginning but throughout the process. The way in which CVD is implemented is a bit less instinctive. Cross-functional teams—for instance, teams involving people from product design, sales, marketing, and program evaluation areas—must work together from the start. Traditionally specialists in each of these areas have worked in isolation, having little or no contact with each other.

Henneberger calls this conventional method the bucket brigade. "All of these people handle a project separately, passing it on through the line without communicating," he says. "The problem is that the needs and interests of the different groups never get heard together." For instance, a salesperson who knows about the market barriers a proposed new product will face never gets a chance to voice these concerns until after the product is designed and introduced to the market. The consequence is that the product may not succeed in the marketplace. Ultimately the product gets redesigned, a step that could have been avoided. It is not unusual, under traditional practices, for product redesign to occur several times. Each time the product comes back to the drawing board, development costs go up and those involved with the process get frustrated.

Henneberger notes that companies have had great success with CVD, mainly because it is a straightforward, applicable process. "Most people already know that being customer focused is important, but these people don't often get the tools to make it happen. CVD is different because it provides the tools to make information on customer needs actionable. So when the outside experts walk away, this process has already attained a life of its own within the organization. It's really about turning information into action, theory into practice—CVD gives you the tools to make quality real."

Matrices: the secret tools

The tools that allow CVD to work so well are a series of five matrices that look like, and hence are commonly called, houses. The matrices create an agenda for action and provide a framework for gathering data, setting priorities on the basis of customer desires, defining measurable performance targets, and documenting decision making. CVD matrices help utilities make difficult choices between competing stakeholder needs, and they generate opportunities to cross-check thinking.

The items in the horizontal rows of the first matrix, or house, are a list of customer needs, ranked in order of their significance. The items in the vertical columns of this house indicate the design targets necessary

TEAM-BASED PROCESS Traditional methods of product and program development involve specialists from various groups working separately on different phases of a project. By contrast, CVD involves a team of workers—from groups as diverse as product design, sales, marketing, and program evaluation—collaborating on a project from start to finish. This approach ensures that the knowledge and concerns of the various groups are considered up front, thereby avoiding time-consuming redesigns after a program or product has been released.

for satisfying the customer needs. The targets include the attributes a product or service must have in order to meet those needs. For instance, the matrix for a lighting program that includes a customer need for low-cost lighting in the horizontal rows might include the design target "investment payback in less than two years" in the vertical columns.

Symbols are used on the grid framed by the customer need and design target axes to indicate the strength of the relationships between the needs and targets. Says Henneberger, "The strength of these relationships offers critical information for decision making." Atop the square-shaped grid is a triangular rooflike grid containing similar symbols, which indicate relationships between the various design targets. For instance, a symbol in the triangular grid might indicate that equipment cost has a negative relationship with bill amount—that is, higher-cost equipment is likely to result in lower electricity bills, since the equipment is likely to be higher quality and more energy-efficient than less expensive equipment. By the same token, lower-cost equipment is likely to result in higher electricity bills.

The very act of constructing the matrices helps a utility team understand the critical relationships between customer needs and the company's ability to satisfy those needs. The matrix approach discourages seat-of-the-pants decisions, impelling team members to make explicit judgments and trade-offs. "When you put something down on paper, you think hard, and if you aren't sure, you investigate," Henneberger says. "By ranking everything on a measurable, quantitative basis, you clarify areas of conflict and work effectively toward customer-driven solutions." While smaller matrices can be written by hand, use of a software program is recommended for performing the more extensive calculations of complex matrices. According to Henneberger, a standard spreadsheet program will work fine. However, two software programs specifically designed for the QFD process are also commercially available.

Inside the houses

The first CVD house, the House of Value, is perhaps the most significant house in the series. As QFD methodologists say, this is where the voice of the customer resides. It is in this house, or phase of the process, that customer needs are identified and prioritized and that design requirements—whether they are related to a program, a technology, or a characteristic of a service—are developed to satisfy those needs.

The term "voice of the customer" has come to represent the prioritized set of customer needs that reflects the relative importance of the needs to the customer. The voice provides the basis for all product and program development in CVD. Experts stress the importance of describing the needs and desires of customers in their own words (obtained through processes like interviews, surveys, focus groups, and market research), rather than filtering the comments through the perceptions of a product development team. This distinction is significant because team members tend to translate customer needs, such as "brighter light," into specific solutions, such as "halogen lamps," at a very early stage—thereby missing out on other, perhaps better, ways of addressing the need.

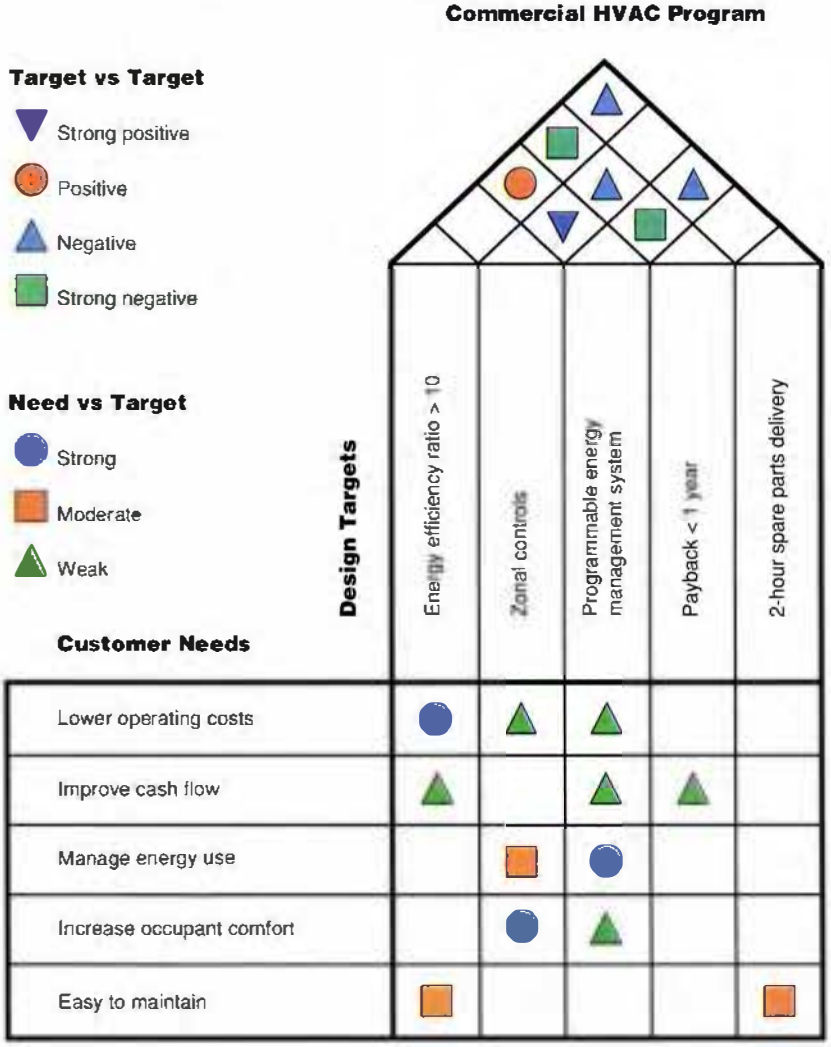
In its CVD process, PSI Energy relied on focus groups and market research to identify customer needs. Customers said they wanted lights that were low in cost, visually appealing, long lasting, easy to control, and flexible. They also wanted the fixtures to be installed by competent workers who were easy to reach and guaranteed installation at a convenient time. And they did not want to spend much time investigating systems or selecting installers. PSI took into account each of these customer needs in developing its program design targets.

Since the voice of the customer drives all decisions in the CVD process, how well an organization documents its customer needs is critical to success. But gathering this information can be time-consuming and expensive. Some utilities may opt to use EPRI's CLASSIFY System as a starting point. A collection of residential, commercial, and industrial customer needs profiles, the CLASSIFY System provides utilities with the information, methods, and tools they require to be customer driven. The system is based on an extensive series of focus groups and interviews with utility customers across the country. Utilities may either use this information directly or supplement the data with information culled from their own service territories. Either way, notes Henneberger, using CLASSIFY will save a significant portion of the cost that would normally be incurred in gathering such data.

The second house, sometimes referred to as the House of Design, is where program or product features are developed to

satisfy the design targets established in the first house. The third house is the House of Delivery. This is where marketing and implementation strategies are created to deliver the product, program, or service developed in the House of Design. Fourth is the House of Management, in which internal control procedures are established to ensure effective implementation. Finally, the House of Evaluation sets up an integrated tracking system that provides feedback on whether the program, product, or service is meeting customer needs and design targets; whether the marketplace is responding as anticipated; and whether the marketing strategy is working.

By all accounts, the first stage of the CVD process is the most time-consuming. But, as is the case with QFD, such close attention up front pays off in the long run. Says Brandom of PSI, "For every hour we invested in planning, we saved two or three hours in implementation. We're also spending considerably less time fixing and changing programs after implementation because of better planning up front. Even though our people in sales still think development takes too long, both sales and our customers are very satisfied with what we're doing."



MATRICES: CRITICAL TO THE CVD PROCESS **A series of five houselike matrices provide the foundation for the CVD process. Shown is an example of the first house/matrix involved in the establishment of a space-conditioning program. The rows on the left list customer needs in the order of their priority. The columns above list the design targets identified to meet those needs. The square grid framed by the two lists indicates the relationships between customer needs and design targets. The triangular grid above the design targets illustrates the relationships between the various targets. By showing the strength of these relationships, the matrices give decision makers a good sense of the trade-offs they may have to make in the design process.**

User perspective

Kansas City Power & Light Company, another early utility industry entrant into the CVD movement, used the methodology to develop a program promoting retrofit, add-on heat pumps to homeowners. Like PSI, KCPL worked closely with EPRI to learn CVD methods. Launched last April, the heat pump program is off to a strong start, says Kevin Murphy, KCPL's manager of marketing programs. "We're getting many more customers to take the leap and install a heat pump," Murphy says.

KCPL's design team considered customer needs for comfort, reliability, and economy; trade-ally needs for a product that is easy to sell and install and will help build business; sales staff needs for a program that satisfies customers and contractors; and corporate needs for a program that more than pays for itself through additional off-peak power sales and positions the company as a customer-focused energy expert. "Before CVD, we looked at everything more from a KCPL point of view," Murphy says. "Now we recognize the need to consider all those with a vested interest in a project's outcome—especially the customer."

Murphy notes that while CVD took some time to learn, not using CVD takes even longer. "We were designing another program at the same time as our add-on heat pump effort, and we thought we didn't have time to use CVD for it," he says. "But our add-on heat pump program was out for months before we finalized the other program." CVD's biggest advantage, Murphy says, is that the planning process allows all stakeholders to voice their needs and concerns up front, thereby avoiding the type of backtracking that typically delays new programs. "We've found that CVD promotes teamwork and allows us to get a better product out more quickly and at lower cost."

HOUSE OF VALUE

The first step in the CVD process is to determine what utility customers really want. The utility's cross-functional team then identifies the design requirements necessary to meet customer needs.

HOUSE OF DESIGN

In the second house, the utility team develops design options for their program, product, or service—options that will satisfy the design requirements established in the House of Value.

HOUSE OF DELIVERY

In the third house, utility team members develop marketing and implementation strategies to deliver the program, product, or service to customers.

Since KCPL's first experience with CVD, the utility has adopted a new emphasis on program evaluation. "Previously, program evaluation was more of an afterthought. And by then, much of the data could no longer be obtained," Murphy says. "For our add-on heat pump program, we have an extensive computer tracking system that monitors sales, customer satisfaction, and program costs." KCPL is promoting CVD to its two state regulatory commissions as one methodological component of its integrated resource planning. "We're letting regulators know we have a process for designing and evaluating programs that we intend to use widely in the future," Murphy says.

Bonneville Power Administration has also found CVD useful—specifically in developing demand-side management programs. As a federal power marketing agency serving the Pacific Northwest and the West Coast, BPA intends to broaden its application of CVD to include power and transmission products. "The basic CVD framework is valid for any product," says

HOUSE OF EVALUATION

In the fifth house, the cross-functional utility team evaluates the program, product, or service to make sure that it is meeting customer needs.

HOUSE OF MANAGEMENT

In the fourth house, team members manage the implementation process, establishing internal controls to ensure that the program, product, or service has been delivered effectively.

John Elizalde, BPA's manager for product development. To train its staff in the CVD process, BPA relied on assistance from EPRI, as did PSI and KCPL. But others—for example, Southern Company Services—have relied on in-house staff.

Southern Company Services' application of CVD goes beyond program development. For instance, the company recently began using the methodology to redesign its customer satisfaction measurement program. According to Charles Plunkett, manager of customer research, the customer satisfaction gauged in this program serves as the basis for employee incentive awards. "We're using CVD to reengineer and refine our satisfaction measurement process," he says. Previously Southern Company Services relied largely on focus groups to define customer needs. Now the company uses one-on-one, in-depth interviews and customer surveys. Plunkett praises voice-of-the-customer practices as providing "one of the clearest linkages I've seen between customer needs and the design and use of that information." The CVD matrices, he notes, provide "a clear blueprint for where we need to concentrate our efforts to improve customer service."

ADVANTAGES OF CVD

- Reduces product development cost
- Compresses product development time
- Builds customer satisfaction and loyalty
- Translates customer needs into specific, measurable targets
- Builds cross-organizational teams for decision making
- Simplifies decision making
- Documents decisions for future reference

A growing trend

Although fewer than a dozen electric utilities currently employ CVD, Henneberger expects this number to increase dramatically in the next few years. As the driving force behind utility operations shifts from regulatory compliance to marketplace demands, utility services need to keep pace, he says. "The costs of being wrong in a competitive industry are significant, so there's a growing market for strategies that enhance customer service, deliver better value, improve system use, and take advantage of creative pricing and delivery techniques."

What utilities have found attractive about the CVD process is that it does not require extensive training or the establishment of elaborate databases, Henneberger says. The technique is simple enough for utilities to employ on their own, with the help of publications like EPRI's recently released how-to guide *Quality Function Deployment: A Customer-Driven Process to Deliver Value* (TR-104663). Those desiring a more speedy introduction may opt for EPRI's two-and-a-half-day, utility-hosted training sessions for up to 30 people.

For its first experience with CVD, PSI engaged an outside consultant to serve as its team facilitator. Now the process is managed by PSI personnel. Brandom recommends that anyone starting out with CVD "do more than just look at a manual." He suggests either attending a workshop such as those sponsored by EPRI, hiring a consultant, or serving on someone else's CVD design team.

While program development is the most common application of CVD, Henneberger believes that many utilities, like Southern Company Services, will find just as much value in applying CVD to other areas. "CVD is especially well suited to facilitating strategic market assessments and company reengineering," he says. "Everyone in the utility industry could benefit from using CVD in one form or another." ■

Background information for this article was provided by Thom Henneberger of the Customer Systems Group's Marketing Tools & DSM Business Unit.

A STRONG FOLLOWING **Quality function deployment, the process on which EPRI's CVD concept is based, was developed at Mitsubishi's Kobe shipyards in 1972 and adopted by Toyota in the late 1970s. In the 1980s, Ford and Xerox pioneered QFD applications in the United States. Today, more than 100 leading U.S. companies—including service firms—use some form of QFD or CVD. Several of these are listed below.**

Manufacturers
Campbell Soup
Colgate
Digital Equipment
Ford
Gillette
Hewlett-Packard
IBM
Kodak
Procter & Gamble
Texas Instruments
Xerox

Service Firms
Fidelity Trust
Fordham University
Hancock Industries
John Muir Medical Center
Ritz-Carlton
University of Michigan Medical Center

Utilities
AT&T
Cincinnati Bell
Cincinnati Gas & Electric
Florida Power & Light
Georgia Power
Kansas City Power & Light
Pacific Gas and Electric
PSI Energy
Southern Company Services

DESKTOP DESIGN

FOR ADVANCED POWER PLANTS

by Taylor Moore

State-of-the-art power plants in this country and abroad are making use of advanced alloys and coatings, design innovations, digital controls, and leading-edge environmental systems. In a four-year collaboration with the Chicago-based architect-engineer Sargent & Lundy, EPRI has produced state-of-the-art software for conceptual design and engineering analysis of these new power plant options. The software takes advantage of the latest in microprocessor technology to gather volumes of knowledge about power plants into one convenient package and to place conceptual design tools in front of every utility engineer.

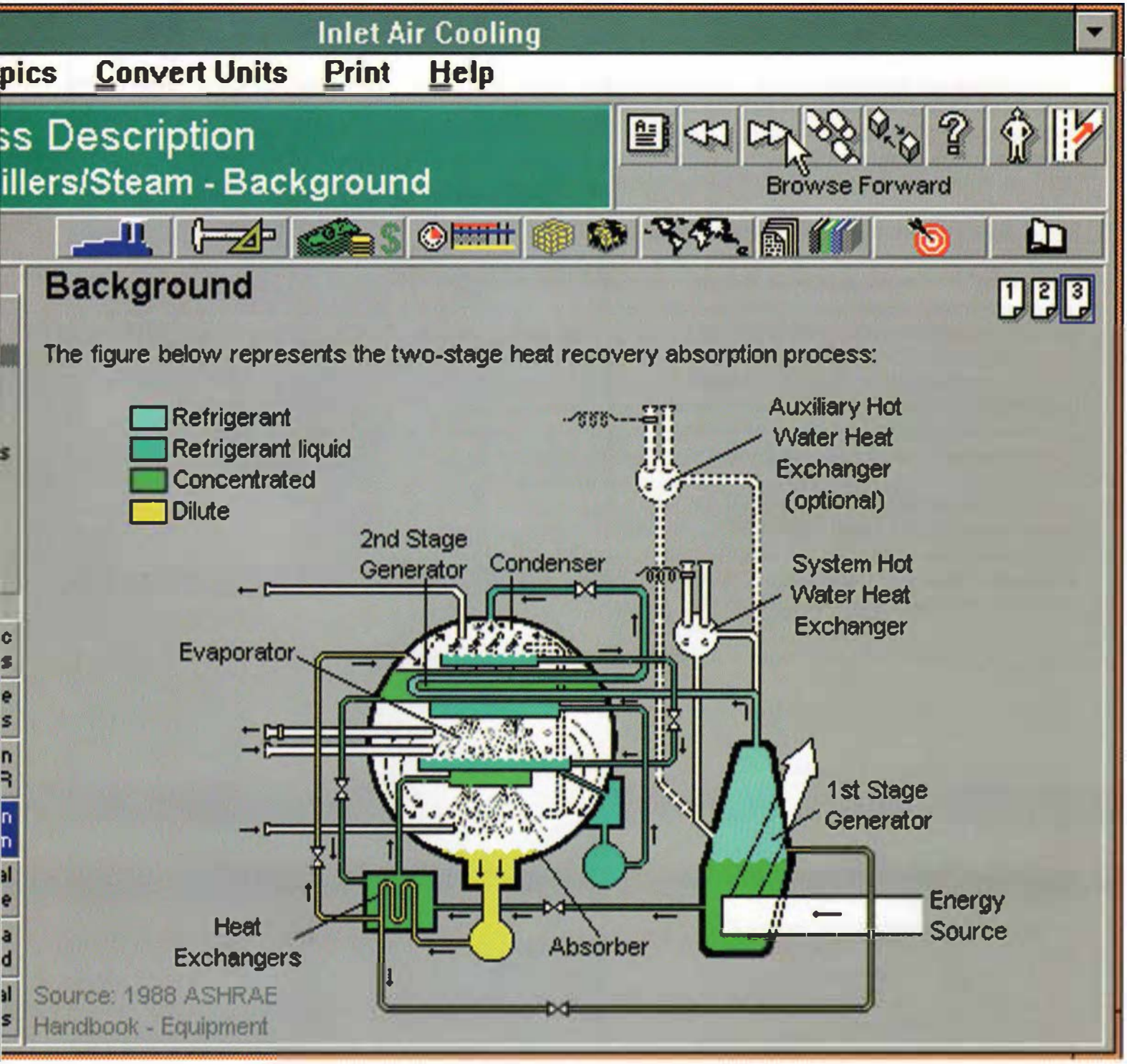
EPRI's State-of-the-Art Power Plant (SOAPP™) WorkStation and the individual technology modules associated with it—the first suite of which spans all major systems of the combustion turbine and combined-cycle plants leading the market today—are CD-ROM-based, multimedia software. The product won several honors in *New Media* magazine's 1993 INVISION Multimedia Awards, including a Gold Medal in the catalog and reference category and an Award of Excellence as one of that year's top multimedia software products.

SOAPP WorkStation™ is a powerful analytical package composed of sophisticated, interlinked calculational engines that combine extensive cost and performance data on commercial power plant designs and equipment and provide a high degree of real-time interactivity. EPRI managers envision SOAPP as the principal technology transfer vehicle for integrating the best current engineering knowledge and design practice with actual cost and performance information on a full array of commercially available power plant equipment.

Designed for use by engineers and managers, both specialist and nonspecialist, SOAPP software enables the rapid generation and evaluation of alternative, project-specific conceptual plant designs. This is done by selecting components from lists of commercial equipment options and entering key design criteria along with site, fuel, and economic parameters. SOAPP WorkStation uses this input to automatically calculate material and heat balances; generate detailed specifications and equipment lists, as well as diagrams of piping and process flows; estimate capital and operating and maintenance (O&M) costs; and provide a financial analysis. And all of this can be reevaluated in light of changes in plant capacity, equipment options, or site or financial criteria. The output designs can be used to produce bid specifications, to support decisions or technology selection, and to aid in planning studies; they can also be used as the starting point for more-detailed computer-aided design (CAD) drawings.

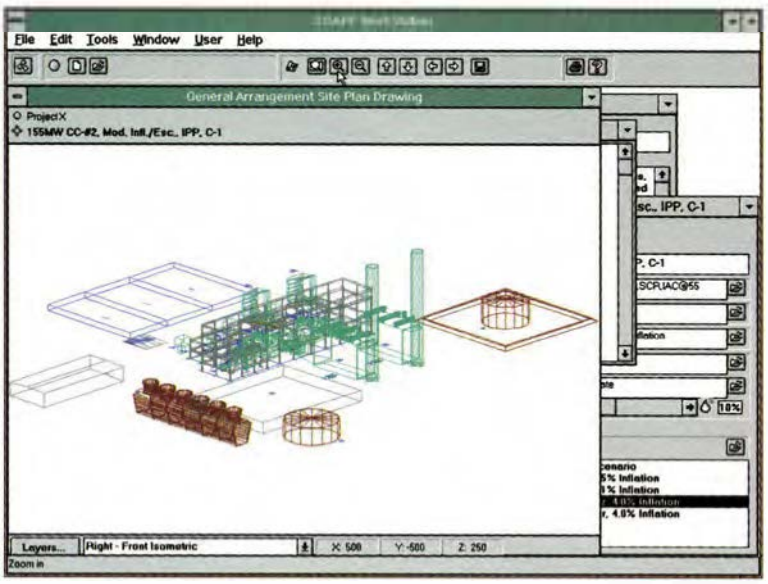
Although the development of SOAPP WorkStation originally focused on state-of-the-art pulverized-coal power plants, particularly their environmental control systems, the principal focus for the first commercial release of the workstation is combustion turbine plants—both simple cycle and combined cycle. This is a response to feedback from utility advisors who have been closely involved in the project. The initial release places a wealth of technical and economic data about the latest combustion turbines and combined-cycle power plants at the ready service of any engineer. Additional SOAPP product releases this year will extend the workstation's comparative analysis capabilities to the evaluation of selected fossil plant repowering options—an area of intense

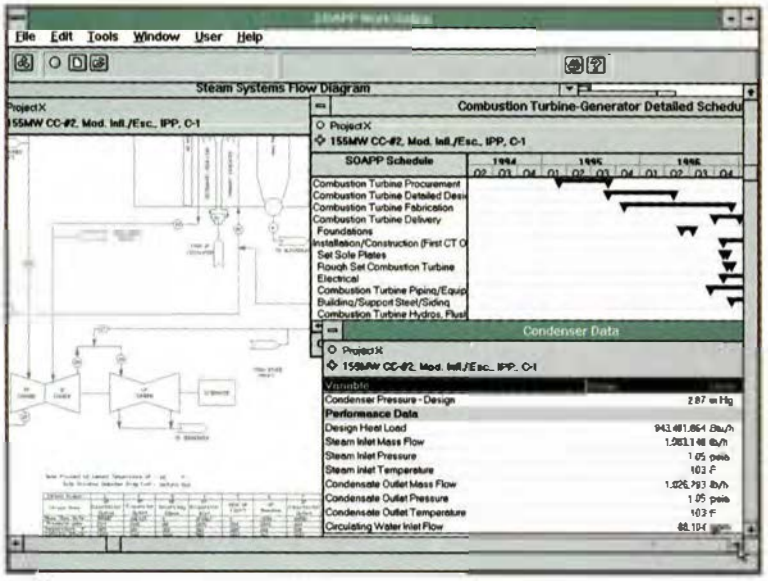
THE STORY IN BRIEF *EPRI has teamed up with Sargent & Lundy to produce a powerful PC software package for engineers that enables conceptual design and analysis of advanced power plants from a desktop computer. Combining the latest cost and performance data from equipment vendors with state-of-the-art design and engineering knowledge, this award-winning multimedia software, called SOAPP, gives users the ability to quickly screen, analyze, and visualize alternative plant configurations. The first series of products focuses on gas turbine and combined-cycle power plants; a related module on the repowering of existing fossil plants is forthcoming. Future modules are expected to extend coverage to other advanced plant options.*



interest among utilities that have aging, underutilized fossil steam generating capacity.

Meanwhile, SOAPP WorkStation may play a role in the Institute's increasing number of international initiatives, including those in the world's fastest-growing power generation market today: the Pacific Rim. "With an unprecedented surge in fossil power plant construction planned in southern Asian countries over the next decade, EPRI's SOAPP WorkStation will help us establish new partnerships and alliances in the Asian-Pacific countries, which hold 40% of the world's population," says Anthony Armor, director of the Fossil Power Plants Business Unit in EPRI's Generation Group. Armor met with utility and power project consortia officials in several Asian-Pacific countries last year.



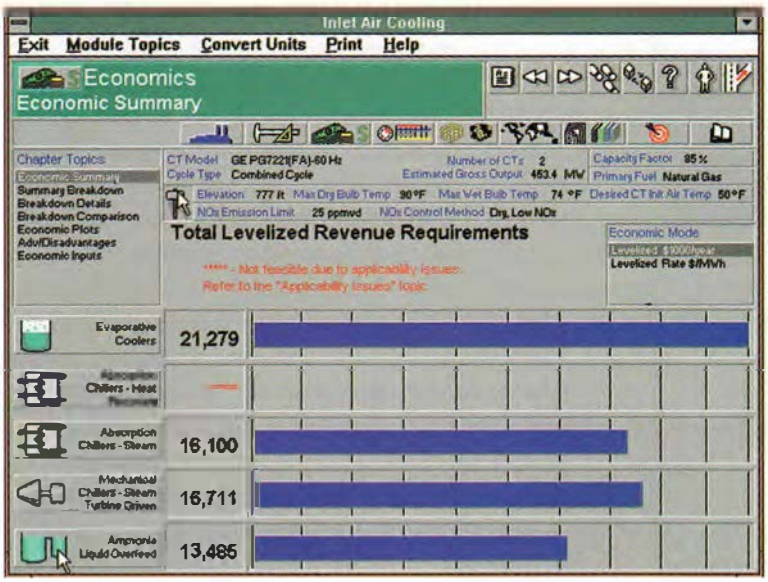


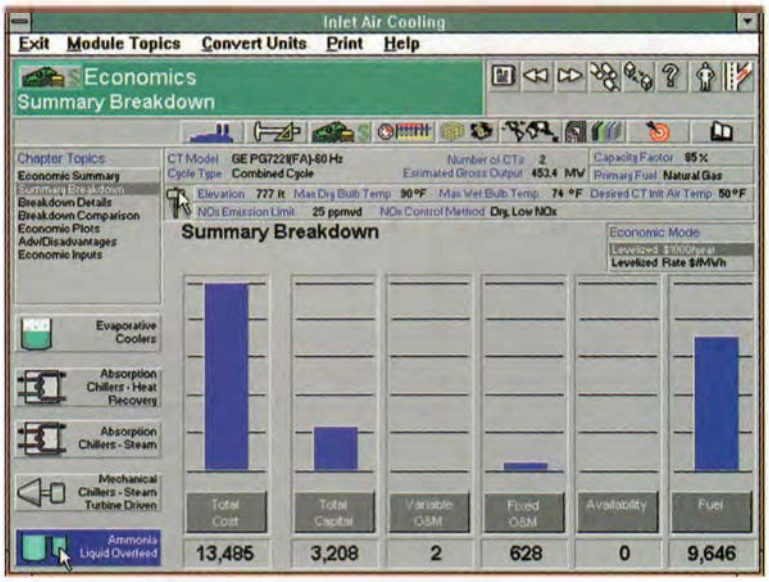
SOAPP WORKSTATION INTEGRATES TECHNOLOGY MODULES **The combustion turbine–combined-cycle part of SOAPP WorkStation provides an integrated software interface for analyzing all the cost and performance data calculated for base-case and specific power plant designs with the 13 individual SOAPP technology modules. SOAPP WorkStation automates the plant conceptual design process and generates a complete set of reports and drawings, including various drawings constructed from a three-dimensional plant model that is created on the basis of user equipment selections. Other drawings can be loaded into AutoCAD-compatible CAD software. The three-dimensional model produced in SOAPP WorkStation can also be used with other software, like Intergraph's MicroStation, to generate a rendered view.**

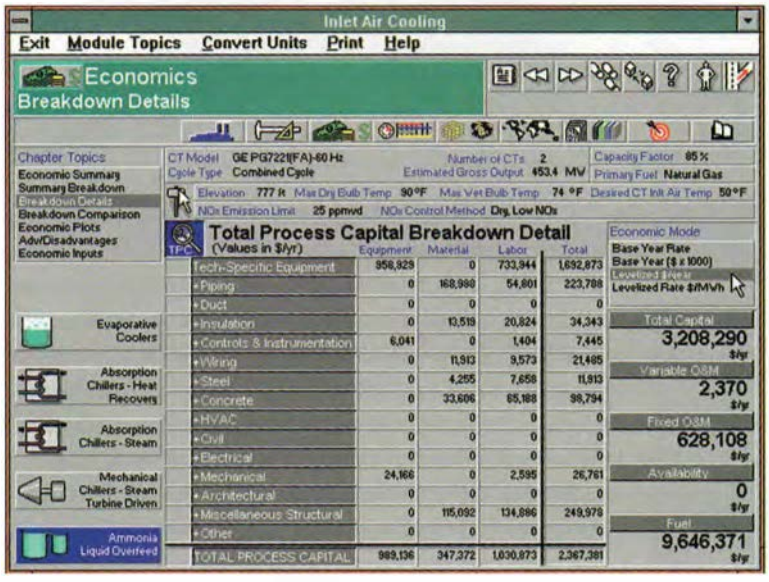
Power plant design tool boosts productivity

EPRI's original R&D interest that led to the development of SOAPP at Sargent & Lundy was a quest for guidelines that would help utility engineers integrate and understand the many individual technological choices that affect an overall plant design's ultimate cost and potential performance.

Explains Stanley Pace, a manager in the Fossil Power Plants Business Unit, "We were looking for ways to bring together







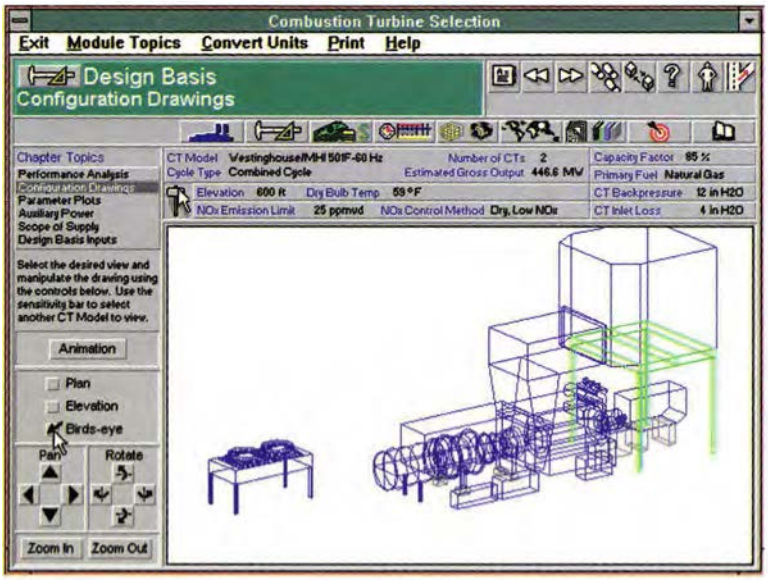
all the engineering and cost data for various technologies incorporating the latest advances in efficiency and environmental performance so the technologies could be evaluated on an equivalent basis. We also wanted the capability to quickly and easily analyze the influence of project-specific conditions, including the potential upstream and downstream effects a particular technology choice has on the overall plant."

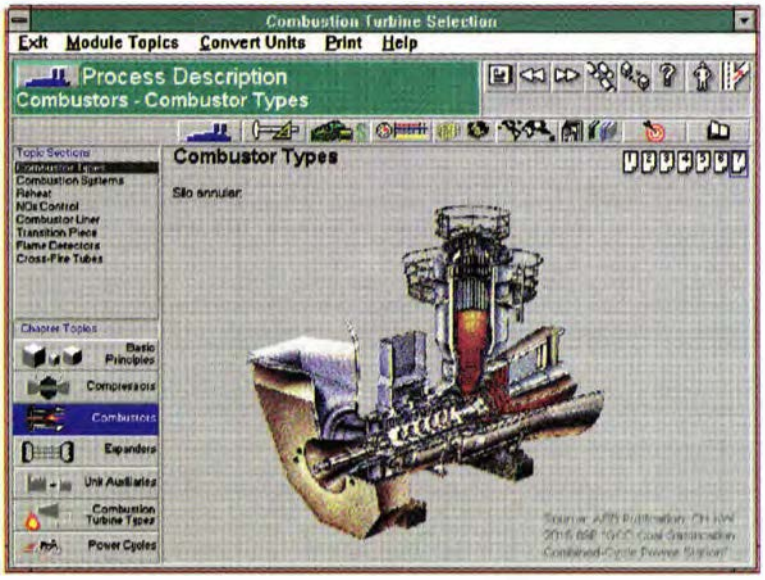
In its proposed workstation, Sargent & Lundy anticipated the availability of CD-ROM mass data storage and sufficiently fast, low-cost microprocessors for desktop computers to enable the intensive engineering calculations needed for such an application, explains William Miller, senior vice president of the company. "Our staff knew that computer hardware and software were coming that would be able to support as robust a product as SOAPP."

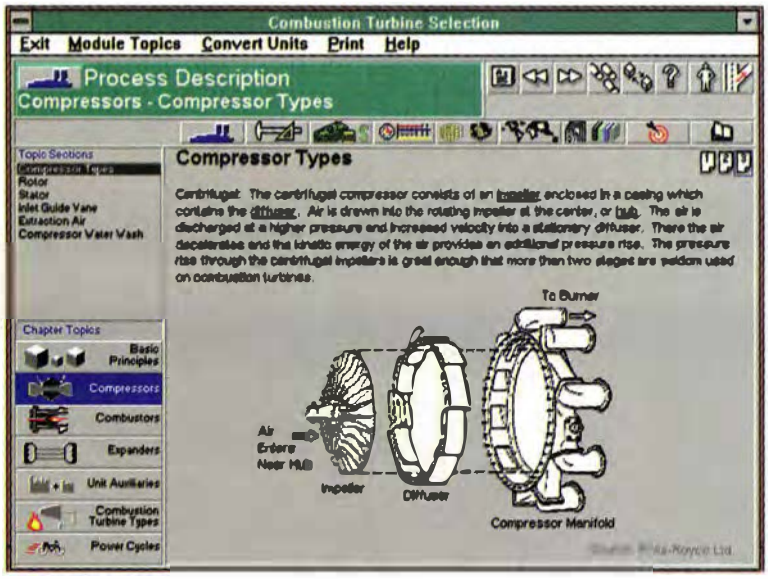
TECHNOLOGY MODULES PERFORM DETAILED ECONOMIC ANALYSIS **In the 13 individual SOAPP technology modules for combustion turbine and combined-cycle power plants, users get in-depth economic and performance data on a complete selection of commercially available equipment and subsystems. Sample screens from one of these modules—inlet air cooling—illustrate how equipment sizing, performance, and cost estimates are automatically recalculated on the basis of user-specified changes in key design parameters. Users can immediately observe the effects of such changes on the relative costs and rankings of alternatives. Embedded levels of detail provide increasing specificity on capital and operating costs. Technical process descriptions are also within easy reach for reference.**

Miller says that the commercial version of SOAPP WorkStation is "absolutely at the leading edge of the state of the art today" in engineering software. He notes that it incorporates "orders of magnitude more sophistication, complexity, and computing power" than the prototype developed for the project, reflecting the input of the utilities that have been actively involved in the project.

Pace says that some benchmarking studies done with SOAPP have shown produc-







tivity improvements of 50 to 1 in the form of reduced engineering time. "Analyses that previously would have required 1000 hours of engineering can be done by one person in 20 hours with SOAPP," he explains.

But both Pace and Miller note that, rather than encroach significantly on the utility market for architect-engineer (A-E) consulting services, SOAPP will likely stimulate a new approach to strategic analysis at the corporate, project, and engineering levels. This will benefit utilities, A-Es, and manufacturers by fostering plant process selection according to financial rather than technical criteria, resulting in more-competitive plant designs. Therefore, managers expect that SOAPP will be embraced and licensed by most A-E firms.

Besides Sargent & Lundy, several other major A-E firms—including Bechtel, Gilbert Associates, and Stone & Webster—participated in the development of SOAPP. These firms were members of an industry advisory committee that also included major vendors of power-generating equipment. Approximately 70 companies provided and reviewed cost and performance data for inclusion in SOAPP.

Pace and Miller agree that the real payoff for utilities that use SOAPP to full advantage is not necessarily in lower costs for engineering services but in greater confidence that a particular choice or decision is

SOAPP TECHNOLOGY MODULES: STATE-OF-THE-ART POWER PLANT DESIGN TOOLS **Each SOAPP technology module focuses on technology alternatives for a specific plant process or component. (Shown are screens from the turbine selection module.) Each module can be used in a stand-alone mode, in which performance and economic evaluations are based on default parameters, or launched from SOAPP WorkStation, which allows users to specify key parameters as the basis for the evaluations. Designed for use with Windows 3.1 software, the SOAPP modules organize information as in a book—with chapters, topics, and sections. Users click on buttons and objects in the multimedia environment to view data, charts, drawings, text, photographs, and video with sound clips.**

optimal—a payoff resulting from SOAPP's ability to evaluate so many more options and possibilities. "SOAPP provides—ingeniously, I believe—the kinds of calculational abilities and options for what-if analyses that engineers have always had to shortcut," says Miller. "I believe that SOAPP users will find that they can be much better engineers because now they can examine many more scenarios quickly and inexpensively."

Focus on combustion turbines

The combustion turbine component of SOAPP WorkStation (SOAPP-CT) is supported by 13 SOAPP technology modules. Each module addresses a key decision area in the power plant and provides tutorial and general reference information in a multimedia format, combining text, photographs, and video clips with sound. The modules provide overviews in layered detail on all major systems and components—overviews that can serve important decision-support training and orientation functions.

The cornerstone of SOAPP-CT is the combustion turbine selection module, which lets engineers evaluate the use of individual CT models in a simple-cycle or a combined-cycle configuration as a function of several key decision sensitivities. The module currently includes a database of over 35 commercially available CT models, including the General Electric Frame 7FA and the Westinghouse 501F. Additional machines will be added to the database as new information becomes available. Annual updates are planned.

Other SOAPP modules address combustor NO_x control, postcombustion emissions control, inlet air precooling, inlet air filtration, heat recovery steam generator (HRSG) configuration, bypass systems, steam turbine selection, duct burner systems, fuel systems, deaerators, condensate preheaters, and cooling systems.

Performance algorithms embedded in the SOAPP software allow the optimization of CT exhaust conditions and HRSG designs. The calculational engine that generates heat and material balances as well as water, steam, and exhaust gas properties was derived from the CYCLE portion of EPRI's GATE/CYCLE program.

Plant conceptual design documentation generated by SOAPP WorkStation includes process flow diagrams, energy and mass balances, equipment and bulk materials lists, piping diagrams, general arrangement drawings, electrical single-line diagrams, major equipment functional specifications, capital and O&M cost estimates, and a construction schedule. SOAPP WorkStation can also be used to generate input for system planning software, such as Energy Management Associates' PROMOD or EPRI's EGEAS. In addition, SOAPP output may serve as input to more-detailed engineering design software used by A-Es.

The SOAPP products for CT-based plants were developed with EPRI base-program funds, with extensive advisory input from a panel of what began as 9 utilities and now numbers 14. The utilities have worked closely with Sargent & Lundy to define the appropriate levels of detail and the features that engineers need most.

Expected to be released later this year are an additional SOAPP technology module for screening repowering options and a component of SOAPP WorkStation for the conceptual design of combined-cycle repowering projects. The development of these products was funded by EPRI and four utility sponsors—Missouri Public Service, Public Service Company of New Mexico, Southern Company Services, and Union Electric Company—through EPRI's tailored collaboration program, in conjunction with site-specific repowering studies at the utilities. The workstation will enable users to input basic information about an existing fossil plant, match it up with CT and HRSG selections, and generate plans and drawings, costs, and performance for a repowered unit.

Utility perspective

Engineers who are familiar with the capabilities of SOAPP are convinced that it will become a major productivity-boosting assessment and evaluation tool that not only will save firms money but will sharpen the analysis of options for least-cost planning

STATE-OF-THE-ART POWER PLANTS IN THE PACIFIC RIM Today's market-leading combined-cycle power plant designs are exemplified by Korea Electric Power Corporation's 1910-MW Seoinchon plant. The plant is currently composed of eight General Electric combined-cycle units, each of which includes a GE 7F gas turbine–generator and a reheat steam turbine–generator. The utility has undertaken a 2000-MW expansion at the plant and has selected GE to provide equipment and services. The additional combined-cycle capacity is expected to come on-line in 1997. (Photo: GE Power Systems)

and avoided-cost-of-generation studies.

"I think it will lead to big savings," says George Powers, a technical specialist engineer at Potomac Electric Power Company (PEPCO) in Washington, D.C. "For utilities that don't plan on building new capacity but that have to go through the evaluations anyway to justify their decisions, SOAPP will allow them to breeze through that work. For utilities that are going to build or that are trying to compete with independent producers, SOAPP will give them better and more-accurate estimates of the costs for various options."

Powers notes that SOAPP "is not going to replace an A-E. It's not that detailed a design tool. But it will be great for conceptual designs. It should become a model for future software platforms, because this is the way they should be done. It's the wave of the future." He says that he hopes to use SOAPP design drawings in CAD form to overlay onto drawings or photographs of candidate plant sites, enabling quick views of how various plant options might appear at a particular location.

"I also expect to see SOAPP used in our least-cost planning analysis. It will give us the ability to come up with better, more-detailed estimates of the cost of options in a short time, on an iterative basis," adds Powers. And the flexibility to modify the capacity of a plant or to examine various cost-performance ratios in the planning stages could give PEPCO the ability to defer capital costs for new construction further into the future. "In the past, this kind of analysis was done by hand and was very time-consuming, so there was no convenient way to do extensive reanalysis or redesign," concludes Powers.

According to Gray Murray, manager of generating-plant performance at Southern Company Services, the value of the quick response available with SOAPP is particularly important in today's business climate. "With all the changes occurring in the marketplace today, including a more competitive environment, there is a definite need for a tool that lets you look at various options for new generating capacity and for repowering existing capacity and lets you quickly screen a large number of options down to a relative few." Murray says that screening options for competitive project bids, a task that previously took several months, should now take only a few days, leaving more time to fine-tune the cost estimates for an optimal design.

"We think that SOAPP shows a lot of promise for assisting us with our generation planning process," says David Brown, a project engineering manager at Central and South West Services in Dallas, Texas. "SOAPP will give us a quick and fairly accurate way of looking at gas-fired simple-cycle and combined-cycle configurations as reference points in our what-if planning scenarios." Brown says that Central and South West used a prerelease version of SOAPP to define a reference plant based on a two-unit combined-cycle plant the company had already analyzed manually in planning studies, adding only basic equipment and site information to the SOAPP reference design. "The results with SOAPP seemed to track pretty well with what we had calculated earlier, which gave us some added confidence that our numbers were reasonably good ones for planning purposes."

A global marketing opportunity

The full computational power of SOAPP WorkStation is best used in optimizing actual preliminary power plant designs. EPRI managers acknowledge that despite SOAPP's anticipated value to U.S. utilities for conceptual analysis and engineering training, a major marketing niche for the product—and an opportunity to add value to SOAPP for EPRI members—lies where many of the world's current power plant design projects are being planned and launched by governments and international consortia: in China, India, Indonesia, Malaysia, Singapore, Sri Lanka, Thailand, and other Asian-Pacific countries. China, for example, is planning to add an average of 21,000 MW of new generating capacity each year until beyond the year 2000; most of it will be conventional coal-fired generation. Malaysia has laid plans to double its installed generating capacity by the turn of the century, as have Indonesia and Thailand; much of the new capacity planned in those countries will be based on natural gas.

"This is where many U.S. power plant builders and equipment manufacturers are going to be doing much of their business over the next 10 years," says EPRI's Anthony Armor. "That's why we want to use SOAPP WorkStation to build alliances with engineering and financial consortia that are putting these new fossil plants in place." Discussions with utility industry officials in the region last year focused on how collaboration might lead to specific cofunding of SOAPP enhancements, including expansion of the equipment database to include Asian suppliers.

"How SOAPP evolves for the Pacific Rim will depend on how EPRI can craft innovative relationships with the utilities, consulting engineers, and equipment manufacturers who are active in the region," explains Armor. "Those players include several of the independent subsidiaries of our members, known as affiliate power producers."

He adds, "Our discussions with European, Japanese, and U.S. companies have emphasized one important aspect. Construction alliances in Asia place considerable emphasis on the financial details of the package being offered. Plant performance and lifetime costs are still important—but not the dominant—parameters in bids for new power plants."

In the meantime, the soon-to-be-swelling ranks of domestic users may come up with a few suggestions of their own about how to make SOAPP even better.

SOAPP is designed for Microsoft Windows 3.1, for use on Intel 486- or Pentium-compatible computers equipped with at least 8 megabytes of RAM and a double-speed CD-ROM drive. SOAPP WorkStation and the SOAPP combustion turbine technology modules are available to EPRI members from the EPRI Distribution Center, (510) 934-4212. SOAPP is also available as part of the Generation Group's Bundled Workstation, which offers EPRI members the opportunity to purchase or lease high-performance personal computers preconfigured with selected software. ■

Background information for this article was provided by Anthony Armor and Stanley Pace of the Generation Group's Fossil Power Plants Business Unit.

CONTRIBUTORS

Technical sources for Journal feature articles

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HENNEBERGER

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PACE

Utility Workers and EMF Health Risks (page 6) was written by Taylor Moore, *Journal* senior feature writer, with information and guidance from two members of the Environment & Health Business Unit of EPRI's Strategic Development Group.

Stan Sussman, target manager for EMF studies, joined EPRI in 1987 as a project manager for EMF exposure assessment studies. A physicist, he previously worked for five years in instrumentation development and earlier managed research in systems modeling. Sussman received an MS from Stevens Institute of Technology and a PhD in applied physics from Stanford University.

Leeka Kheifets, an epidemiologist, came to EPRI in 1988 after two years in occupational health surveillance and management at Syntex Corporation and three years as a biostatistician at Environmental Health Associates. Kheifets received a BS in mathematics from the University of Yerevan (Armenia); she also has an MA in statistics and a PhD in epidemiology, both from the University of California at Berkeley. ■

Customer Value Deployment: Turning Information Into Action (page 18) was written by Peggy Waldman, science writer, with assistance from **Thom Henneberger,** manager for product development and marketing with the Customer Systems Group's Marketing Tools & DSM Business Unit. Henneberger joined EPRI in 1988 after nine years with the Florida Public Service Commission in a variety of positions—most recently as chief of system planning and conservation. He has a BS in physics from Fairfield University and an MS in the same subject from the University of Cincinnati. ■

Desktop Design for Advanced Power Plants (page 24) was written by Taylor Moore with information and guidance from two members of the Generation Group's Fossil Power Plants Business Unit.

Anthony Armor, director for fossil power plants, joined EPRI in 1979 after 11 years at General Electric, first in the Large Steam Turbine-Generator Division and later as program manager for superconducting generators. Armor received a BS in mathematics and an MS in mining engineering from the University of Nottingham (England).

Stanley Pace, international manager for fossil power plants, joined EPRI in 1984 after six years with United Centrifugal Pumps of San Jose, California. He earlier worked for Combustion Engineering for five years; before that, he was an instructor in the U.S. Navy Nuclear Power Program for four years. Pace received BS and MS degrees in mechanical engineering from Lehigh University. ■

Advanced Appliances

EPRI Launches Laundry Products Initiative

With the aim of accelerating the deployment of laundry appliances that can reduce energy use and save water, EPRI has launched its Laundry Products Initiative. The stars of this R&D and commercialization effort are the microwave clothes dryer and the horizontal-axis clothes washer.

The microwave dryer, being developed for EPRI by Thermo Energy Corporation and ASTeX/Gerling Laboratories, is expected to dry clothing as much as 65% faster than conventional dryers. This increased speed allows the dryer to keep pace with a washer, so users don't experience a wet-clothes backup as washed clothing sits waiting for the dryer cycle to end.

The technology works by evaporating water molecules without—in contrast to conventional dryers—excessively heating the fabric itself. With microwave technology, drying occurs at 105°F, compared with 170°F for conventional residential dryers and even higher temperatures for commercial dryers. The lower temperature means less wear and tear on fabrics. In fact, researchers expect that the technology will be able to safely dry some heat-sensitive fabrics that currently require dry cleaning.

Field testing of the microwave clothes dryer, which will take place in the homes of electric utility customers, will get under way this year at nine test sites across the United States. EPRI is also planning to develop and demonstrate a commercial dryer capable of handling 100 pounds of clothes. According to John Kesselring of EPRI, manager of the Laundry Products Initiative, the microwave dryer is expected to be commercialized within three years. The potential U.S. market for the microwave clothes dryer is significant, with over 4.5 million new dryers sold annually in the residential market alone.

The potential U.S. market for the horizontal-axis washer is also considered significant, since at least 7 million new washing machines are sold in the residential market each year. In a horizontal-axis washer, the wash tub revolves around a horizontal, rather than a vertical, axis. Currently, the U.S. residential washing machine market is dominated by vertical-axis, top-loading machines, which account for over 98% of residential sales. The vertical-axis machine is only slightly less dominant in the U.S. commercial market. In Europe, however, the horizontal-axis washer (in both top-loading and front-loading models) is the washer of choice.

Market analysts believe that the advantages of the horizontal-axis washer under development by Maytag and EPRI give it a strong chance for success in both the residential sector and the commercial sector. In general, horizontal-axis washers reduce water use by at least one-third. And since water heating accounts for up to 90% of the energy used in conventional residential washing machines, energy use will also decline. In fact, energy savings are expected to top 50%. With a higher washer spin speed, energy savings could reach more than 60%.

In spite of such advantages, EPRI researchers say, a market transformation will be needed to ensure acceptance of the new technology. This is why EPRI initiated the high-efficiency laundry metering and marketing analysis, or THELMA, project. This effort, also part of the laundry initiative, will produce research results to guide utilities in encouraging market acceptance of the horizontal-axis washer.

Currently through THELMA, researchers are conducting a comprehensive market assessment to determine how best to target U.S. consumers and how to develop their interest in the horizontal-axis washer. The assessment involves surveys and interviews with field test participants and focus groups with nonparticipants. (Field tests of the new washer—planned for up to 100 sites across the country—got under way this year and are expected to be completed in 1996.)

THELMA participants currently include Seattle City Light, Seattle Water Department, Bonneville Power Administration, Tacoma Public Utilities, Idaho Power, Puget Sound Power & Light, Snohomish County Public Utility District No. 1, Los Angeles Department of Water & Power, Ontario Hydro, Tampa Water Department, and the U.S. Bureau of Reclamation. There is still time for new utilities to join THELMA or other laundry initiative efforts. Participants may specify how their funds are to be spent. They may also request marketing studies targeted to their service territories, seminars to introduce the new products to their marketing staffs and trade allies, and other consulting services to help develop their markets.

■ *For more information, contact John Kesselring, (415) 855-2902.*

Energy Storage

Batteries, SMES Considered for Alaska's Railbelt System

Spanning a 600-mile stretch of mountainous terrain encompassing Fairbanks and Anchorage—a region that includes more than half of Alaska's population—is an isolated electric grid not connected to the mainland United States or to Canada. The grid is known as the interconnected Railbelt system—"Railbelt" for the region itself, the location of Alaska's major railway line, and "interconnected" because the grid system is something of a novelty in a state where many communities get their electricity from stand-alone power stations.

Life along the interconnected Railbelt system is not ideal, at least in terms of electricity. Because of the islandlike nature of the electric grid, generator outages (which occur every few weeks, on average) can thrust entire blocks of the system—including businesses, homes, and schools—into darkness. The problem occurs most frequently during the frigid winter months, when electricity demand climbs to a 680-MW peak.

A recent study sponsored by the U.S. Department of Energy, in cooperation with three of the largest Railbelt utilities—Golden Valley Electric Association, Chugach Electric Association, and Anchorage Municipal Light & Power—indicated that battery technology could help address the problems of the Railbelt system.

Invited to review the study results, EPRI recommended a more detailed feasibility assessment, including the development of accurate cost data and a more sophisticated benefits analysis. As a result, Golden Valley, Chugach, and the National Rural Electric Cooperative Association teamed up with EPRI to embark on such an assessment. (DOE is funding a small portion of the first phase of this project.) The assessment, which got under way last summer, includes a cost-benefit analysis of battery and superconducting magnetic energy storage (SMES) technologies. In parallel, Anchorage Municipal Light & Power is pursuing a separate study—sponsored by the U.S. Department of Defense—of the potential for SMES in the Anchorage area. EPRI is funding a small portion of this study and is overseeing both studies to ensure that there is no duplication of effort. Results of the studies will be available to all participants.

As Steven Eckroad, EPRI's manager for the battery and SMES assessment, explains, either batteries or SMES technology could fulfill the role of static VAR compensators (SVCs), which are already employed on the Railbelt's transmission system to compensate for sudden changes in voltage. However, batteries or SMES could offer additional benefits, such as spinning reserve. Battery- or SMES-based spinning reserve would enable the Railbelt utilities to maintain a 60-Hz frequency when problems like generator outages occur.

Currently, when a generator outage occurs on the Railbelt system, frequency decays rapidly, and relays automatically spring open to shed load and prevent further decay that could shut down the entire system. Load shedding is necessary because the Railbelt system is isolated and cannot receive power from a nearby grid. Outages resulting from load shedding can last anywhere from a few minutes to half an hour.

According to Eckroad, battery and SMES technologies can respond to such predicaments within 10–20 milliseconds, compared with 3–60 seconds for a backup generator that is already on-line and 15–30 minutes for a generator that must be started up. This kind of rapid response could effectively prevent disruption of electric service.

The ongoing cost-benefit assessment for battery and SMES technologies is expected to be completed this summer. Researchers are relying on EPRI-developed transmission stability models and the Institute's DYNASTORE code in conducting the assessment. The results will be closely reviewed by participants in a related project funded by the state of Alaska and Alaskan utilities. Known as the northern intertie project, this effort originally called for the installation of SVCs along the Railbelt system. The project sponsors are now considering the use of batteries and are awaiting results from the collaborative, EPRI-led study.

Once the cost-benefit analysis is completed, the study team will request proposals from manufacturers of the technology selected. Ultimately, the team will establish a demonstration plant and monitor its performance.

Although the battery and SMES assessment focuses on Alaska's Railbelt system, key results will be applicable to rural electric cooperatives and other utilities in the rest of the country.

■ *For more information, contact Steven Eckroad, (415) 855-1066.*

Efficient, Ozone-Friendly Supermarket Refrigeration a Recognized Success Story

EPRI's efficient supermarket refrigeration test store project has been recognized by Renew America as an environmental success story. EPRI has worked with Safeway Stores since 1985 to demonstrate high-efficiency electric refrigeration technologies at a supermarket in Menlo Park, California. Recent results show that environmentally preferred hydrofluorocarbon (HFC) refrigerants, developed as alternatives to compounds suspected of damaging the earth's protective ozone layer, can also be more energy-efficient than either chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs).

In the project at the Menlo Park Safeway, which involved 25 doors of multideck frozen food cases and 29 doors of ice cream cases, EPRI researchers replaced CFC refrigerants with HFCs. To improve energy efficiency, they substituted external liquid-suction heat exchangers for subcooling compressors. Results showed that with the heat exchangers and with fine-tuning of the display case expansion valves, the use of HFC refrigerants required less energy and produced a higher energy-efficiency ratio than did operation on HCFCs or CFCs with subcooling compressors.

"EPRI's refrigeration technology work has helped build a partnership between the supermarket industry, equipment manufacturers, and utilities to increase supermarket equipment efficiency and environmental friendliness," says Mort Blatt, manager for residential and small commercial systems in the Customer Systems Group. Adds Mukesh Khattar, who managed the research: "This project offered electric utilities and the supermarket industry a way to test alternative refrigerants and energy-efficient designs under real operating conditions."

Refrigeration systems are the biggest users of energy in supermarkets, accounting for half of their total energy consumption. Supermarkets, in turn, account for about 4% of U.S. commercial-sector electricity consumption.

The winners of Renew America's annual awards were selected by the National Awards Council for Environmental Sustainability, a coalition of 60 environmental, community, government, and business organizations. The selections were made from over 1600 applicants for projects involving energy efficiency, water conservation, solid and hazardous waste management, and endangered-species protection. Awards were presented to the winners in 24 categories at a ceremony in Washington, D.C., in January.

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

Static Condenser for Power Transmission Ready for TVA Demonstration

An April dedication is scheduled at the Tennessee Valley Authority's Sullivan substation near Johnson City, Tennessee, for a facility to demonstrate the most recent technology element for solid-state electronic power transmission within EPRI's FACTS (flexible ac transmission systems) program. The advanced control system being installed at the substation features the first commercial prototype of a static condenser to provide transmission voltage support without the need for large external capacitor banks or reactors.

Developed with EPRI and TVA funding by Westinghouse Electric Corporation, the static condenser system, or STATCON, is the latest in a series of advanced power control devices developed under EPRI's long-range FACTS program. The program aims to substantially increase the effective capacity, efficiency, and reliability of high-voltage power transmission through the application of a variety of control systems based on power electronics.

"Solid-state electronic devices like STATCON can increase the operational reliability of our transmission system while decreasing capital and maintenance costs," says Bill Museler, TVA vice president for transmission and power supply. "Further, they allow us to make optimum utilization of the trans-

mission system capabilities under open-access requirements."

The development of STATCON became possible with the availability of gate-turnoff (GTO) thyristors, high-power electronic switches that enable the condenser to regulate voltage without costly external elements and also to rapidly damp even major power system disturbances. The technology provides "faster and more precise control of power flow," according to Aris Melissaratos, Westinghouse vice president for science, technology, and quality. "In addition, we estimate that STATCON will need about 60% less real estate and installation labor than conventional control equipment."

The commercial prototype installed at the Sullivan substation is rated 200 MVAR, with a continuously variable output of −100 MVAR to +100 MVAR.

In the future, STATCON may be used to connect a stored-energy source—such as a battery bank or a superconducting coil—to a transmission line and provide real power to protect critical loads during outages. Additional benefits are anticipated as metal oxide semiconductor-controlled thyristors eventually replace GTO thyristors.

"As the construction of new transmission lines becomes more difficult, utilities are looking for better ways to control and optimize their existing power systems," says EPRI's Karl Stahlkopf, vice president for power delivery. "Our FACTS program provides utilities with the enabling technology to meet their goals, and STATCON is a key component of this technology."

■ *For more information, contact Abdel-Aty Edris, (415) 855-2311.*

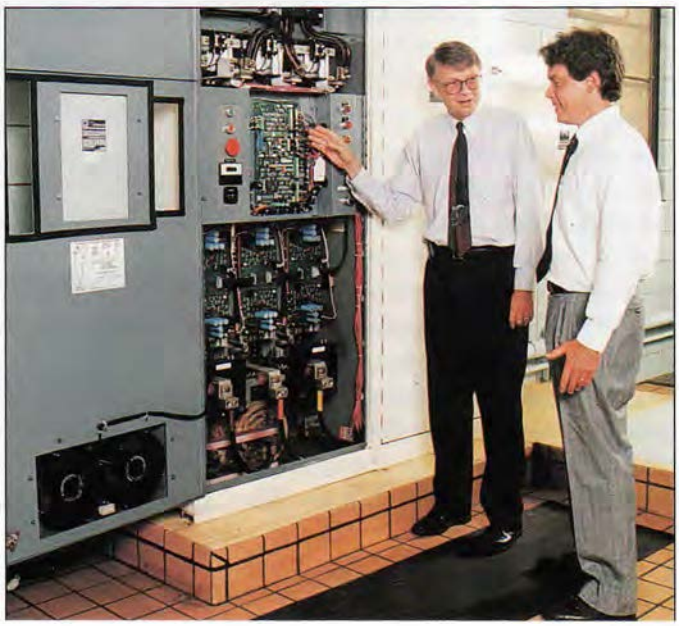
Adjustable-Speed Drives Cut Power Costs for Water Pumping

Jersey Central Power & Light Company held a technical roundtable to spread awareness among some of its large customers about the benefits of using adjustable-speed drives in centrifugal pumping applications. ASDs conserve electricity for pumping when flow rates vary and motors operate at less than full load for a large percentage of the time. JCP&L issued a challenge to its customers to help develop innovative ASD projects that would both save energy and reduce operating costs. EPRI's recently launched Community Environmental Center assisted the utility by supplying information on ASDs and sharing its experience with similar applications. The center works to promote the use of electro technologies in water and wastewater treatment and to encourage the development of collaborative programs between electric utilities and their municipal water and wastewater system customers.

JCP&L and New Jersey American Water Company, one of its large customers, formed a partnership that would benefit both utilities. New Jersey American provides water service to more than 312,000 customers in all parts of the state. In 1991, the two utilities worked together and shared expenses on a pilot project to install ASDs on four of the water utility's pumping units with a combined 650 hp. Rebates from JCP&L covered 50% of the installed cost of the ASDs. The ASDs were projected to save $350,000 in energy costs, with cost recovery periods for the equipment ranging from 2 to 18 months.

The ASD retrofit program at New Jersey American Water proved so successful in improving system operations (for example, in reducing water-main breaks from water hammer) and in lowering operating costs that the company has expanded the program to 18 installations. Other municipal water systems with variable pumping requirements can benefit from the experience of JCP&L and New Jersey American Water in evaluating their own operations.

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



Exploratory Research

Exploring Electrochemical Synthesis

by Robert Weaver and Fritz Kalhammer, Strategic R&D Business Unit

Scientists funded by EPRI are currently exploring the synthesis of commercially important compounds via novel electrochemical pathways. Electrosynthesis methods, which employ electricity to generate products from reactants dissolved in conductive (electrolytic) media, may offer promising—more efficient and environmentally benign—alternatives to the conventional synthesis methods used by the chemical manufacturing industry.

Chemical reactions involve the conversion of one or more compounds into other compounds. Chemical processes are mediated at the atomic level by electron transfer, but in industrial practice they are normally driven by thermal energy supplied by fossil fuels. In electrochemical synthesis, the key reactions are driven directly by electric current—the flow of electrons. Because the applied voltage and thus the driving energy can be exactly regulated, electron transfer—and with it the path and the rate of chemical reactions—can be controlled much more readily than when conventional methods are used.

A typical electrochemical reactor apparatus, or cell, consists of a voltage and current source connected to a pair of electrodes immersed in an electrolyte bath containing dissolved reactants (Figure 1). The application of a voltage causes current flow from the electrodes to the solution, which drives electrochemical reactions at the electrode surfaces. Associated secondary reactions are possible at either the electrode-electrolyte interface or in the bulk electrolytic solution. The current is carried through the bulk of the electrolytic medium by ionized species, such as various salts added to the liquid medium.

Electrochemistry presents the possibility of manipulating the course, rate, and end results of a wide variety of chemical reactions. In electrosynthesis, this enhanced control can be employed to improve yield, decrease side reactions and environmental wastes, and permit the creation of new products. For example, this type of control can increase the production of molecules having the desired chirality, a structural property of organic molecules that is critical to the biochemical activity of many biochemical and pharmaceutical compounds. The world market for chiral drugs currently exceeds $35 billion a year, with annual growth expected to exceed 5%.

Current chemical industry applications

Electrochemistry has been used for the production of a limited number of chemicals for almost as long as electricity has been commercially available. Electricity-based approaches have served as the primary means of generating chloralkali chemicals (chlorine and sodium hydroxide) since before 1900, for instance. Another example is aluminum, which in the nineteenth century had a street value roughly equal to that of gold because con-

ABSTRACT *Electrochemical techniques, which permit enhanced control and selectivity in carrying out chemical reactions, hold promise for significantly expanding electricity use in the chemical manufacturing industry. Control of reaction pathways by electrochemical synthesis may facilitate the preparation of existing and new compounds, reduce undesirable by-products, and improve selectivity in the production of orientation-specific drugs and chemicals. However, the science base for electrosynthesis is not yet well developed, and the chemical industry is unfamiliar with the advanced electrochemical engineering concepts and techniques through which economically competitive industrial electrosynthesis processes could be developed. In 1992, EPRI and the National Science Foundation launched a collaborative exploratory research initiative to increase understanding of electrochemical synthesis. This effort has already identified potential new applications by the biochemical and pharmaceutical industries, as well as several possible solutions to problems that have limited the usefulness of electrosynthesis processes. The results to date suggest that some of the obstacles to widespread application of these processes could soon be overcome.*

ventional processing methods were inefficient and costly. An effective electrolytic technique—the Hall process—made commercial production of aluminum possible and resulted in its widespread application in aeronautics and many other fields. At present, the electrochemical production of chloralkalis and aluminum consumes about 2% of the total U.S. electricity output.

However, large-scale efforts to produce organic (carbon-based) compounds by electrochemical methods have proved less successful. Organic compounds are both more complex and less soluble in conductive solvents than are common inorganic materials. Also, many organics can deteriorate under the oxidizing conditions at the anode of a typical electrochemical cell, resulting in electrode fouling and significant loss of reaction efficiency.

At present, organic electrosynthesis is employed on an industrial scale only in an intermediate stage of nylon production. It is noteworthy, however, that the production of just this one chemical (adiponitrile) uses several hundred megawatts of electric generating capacity. Smaller quantities of several expensive organics are also produced by electrolytic processes, and new reactions continue to be discovered in worldwide research, suggesting considerable promise for organic electrosynthesis. Once the chemical industry has gained a better fundamental and practical understanding of organic electrochemical reactions, new, high-value applications of electricity are likely to be created. This expectation is motivating EPRI's R&D investment in this field.

EPRI research

EPRI is cooperating with the National Science Foundation (NSF) to advance the understanding and practical application of electrochemical processes and thereby expand the use of electricity in chemical production. A joint workshop, held in 1990, identified key research needs and promising processes. On the basis of the workshop conclusions, EPRI and the NSF launched a collaborative electrochemical synthesis research program. Resulting NSF grants and EPRI contracts are now supporting 11 projects aimed at building a fundamental understanding of electrochemical synthesis and fostering the development of new process concepts and methods. The five projects currently sponsored by EPRI are highlighted below.

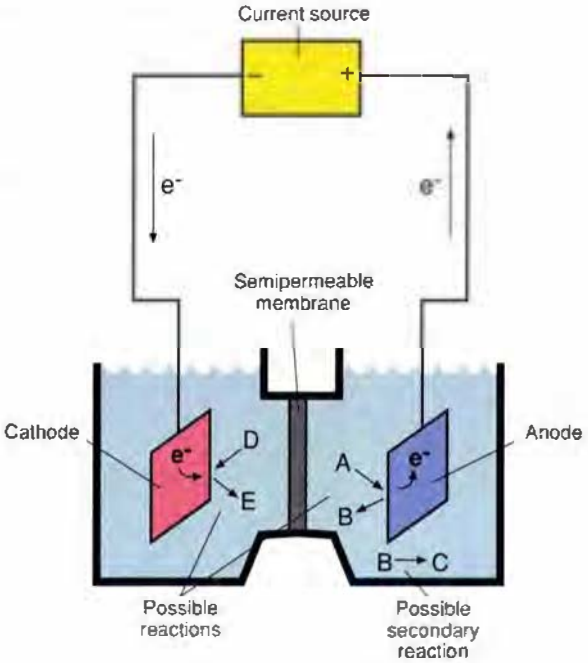
Supercritical electrolytes Scientists at the University of Detroit Mercy are investigating the use of supercritical fluids as a new approach to increasing electroorganic reaction rates (RP8060-4).

The typically low solubility of organic reactants in aqueous electrolyte solutions results in low reaction rates, a serious hindrance to the development of practical electrochemical methods. The use of supercritical solvents could help overcome this problem. These solvents are normally gaseous compounds that, when subjected to high pressure, exist in an unusual fluid state that is neither liquid nor vapor. Because of that property, many reactants are highly soluble in such fluids, with concentration increases of 100 times or more possible for relatively insoluble compounds. In electrochemical applications, this effect will allow much higher rates of reactant transport to electrodes, and that, in turn, can substantially boost the rate of conversion to products at the electrode surfaces.

The use of supercritical solvents also offers another advantage: small changes in pressure produce large changes in solvent density, causing the solubility of dissolved components to change dramatically. This phenomenon has prompted the application of these fluids in separation processes, the best known being the use of supercritical carbon dioxide to remove caffeine from coffee beans. In electrosynthesis, this property could allow easy, low-cost isolation of reaction products, a very important factor in the economics of chemical processing.

Despite the expected benefits, to date the use of supercritical fluids in chemical and electrochemical processing has been limited because of the high temperatures and pressures typically required. Water, for example, becomes supercritical only at 374°C and 220 atm. In EPRI-supported work, the researchers at Detroit Mercy have developed an innovative cell for organic electrosynthesis under high-temperature, high-pressure conditions. In laboratory experiments, supercritical solvents have been employed to produce simple organic products—such as dimethyl carbonate, $(CH_3O)_2CO$. Current efforts focus on the long-term goal of generating common carbon-based compounds from carbon dioxide, a safe, readily available substance that becomes supercritical below about 30°C and above 75 atm.

Figure 1 Electrosynthesis, which uses an electrochemical cell to mediate chemical reactions, offers enhanced process control through the controlled transfer of electrons (e^-). A typical cell consists of a voltage and current source connected to a pair of solid electrodes immersed in a conductive bath containing dissolved reactants. The application of electric current drives reactions at the electrodes and, in some cases, secondary reactions of the electrode reaction products in the electrolyte bath.



Electrocyclization Researchers at the University of California at Santa Barbara are exploring the use of electrocyclization reactions for the selective electrochemical production of biochemical compounds having specific chirality (RP8060-5).

Chirality refers to a compound's struc-

ture—the spatial arrangement of its bonds. Two compounds that have exactly the same number and kinds of atoms and bonds might be thought to be identical, and in elemental analysis they would be. But if the bonds are arranged so that it is physically impossible to superimpose one molecule on the other, as is true for those in Figure 2, the two compounds are structurally different. (These different configurations are referred to as the R and S forms of compounds.)

Because structural differences may lead to differing chemical reactivity, chirality is important in many biological applications. Research strongly suggests that there can be significant differences in human physiological responses to mixtures containing equal amounts of R and S forms and mixtures having more of one structure than the other.

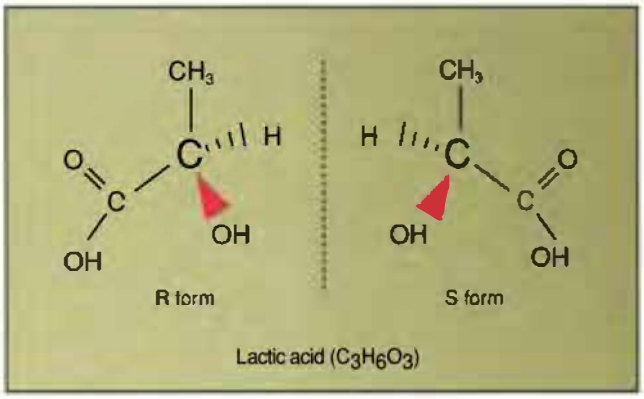
Electrocyclization processes generate chiral organic compounds by forming cyclic molecules from straight-chain precursors. In EPRI-funded work, scientists have identified an electrochemical mechanism for this class of reactions and have applied this understanding to facilitate the electrosynthesis of several common compounds with desired chirality.

Also, investigations of cell conditions, electrolyte parameters, and electrode characteristics have revealed several promising process simplifications. At present, electrocyclization and related reactions are being studied for use in the synthesis of much more complex chiral products, such as the potent antimalarial agent arteannuin B.

An important side benefit of this research is the training of several young electrochemists in advanced electrosynthesis techniques, a key step in the eventual adoption of such techniques by the chemical industry.

Enzyme electrocatalysis Scientists at Wesleyan University are applying electrocatalysis in attempts to enhance synthesis efficiency (RP8060-3). In particular, this project targets the electrochemical regeneration of the coenzymes used in the protein-catalyzed (enzymatic) production of amino acids.

Figure 2 Many complex molecules are chiral; that is, they exist in two forms that have the same chemical components and bonds but have different "handedness" and often different biophysical properties. Lactic acid is one such chiral compound. The chemically identical forms shown here differ in physical orientation: they are mirror images and cannot be superimposed on each other. As a result, they may react differently in some biological processes.



The synthesis of amino acids such as phenylalanine (a key component in NutraSweet sweetener) is a rapidly growing industry. The high cost of the enzyme catalysts and coenzymes that mediate these complex organic syntheses necessitates catalyst recycling. Because electrochemistry has substantial promise for economical enzyme regeneration, many possible electrochemical recycling schemes have been devised in recent years (Figure 3). The deployment of practical processes has, however, been hindered by short catalyst lifetime.

At Wesleyan, a new procedure has been devised for enhancing the electrochemical effectiveness—and thus regeneration—of an enzyme employed in the production of lactic acid, which is commercially important to the food industry. By immobilizing a catalyst precursor and a coenzyme in a polymer film on a carbon electrode, scientists have been able to produce and regenerate the enzyme catalyst directly and efficiently by electrochemical means. In laboratory experiments, this easily applied process has extended catalyst lifetime almost tenfold.

The researchers have also, for the first time, crystallized the enzyme catalyst itself, which is highly unstable in solution. They are now working with biochemists to develop an active, stable form of this compound and with chemical engineers to scale up the overall electrocatalysis procedure for possible industrial use. In addition, electrochemical conditions for the regeneration of other important enzymes are under study.

Antifouling electrode coatings North Carolina State University scientists are investigating polymer coatings as antifouling agents for the electrodes used in organic electrosynthesis (RP8060-6).

A number of organic synthesis reactions (especially oxidations) are driven by redox reactions, which involve chemical interaction with the oxidized form of a metal ion in solution. The reduced form of the metal ion created in such a reaction is then regenerated at one of the electrodes. At present, however, this approach is not widely applied because large organic molecules subjected to oxidizing conditions often foul the electrodes used for reactant regeneration, reducing cell efficiency to uneconomical levels.

In EPRI-supported research, scientists have established that specific ion-selective coatings can reduce and, in some cases, eliminate organic fouling of electrodes. These coatings prevent large, uncharged organic molecules from contacting an electrode and depositing on it; remarkably, they do not block electrode access and interactions for smaller, charged reactants.

On the basis of this finding, a number of polymer membranes have been studied in conjunction with common cerium-based redox reagents in sulfuric acid and methylsulfonic acid solvents; platinum, glassy carbon, and other electrode substrates were used. Effective membranes and coating methods have been identified for specific regeneration processes, and two patent applications have been filed. Ongoing work is targeting generic antifouling applications.

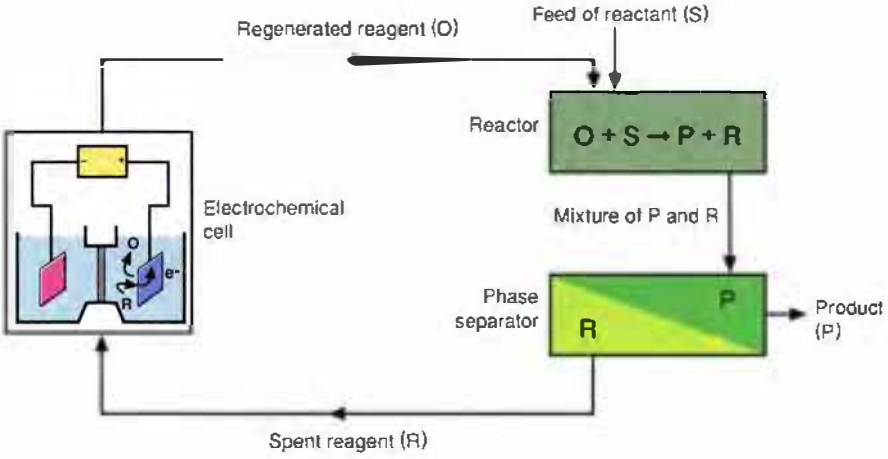
Superconductor fabrication In a second electrode-oriented project, researchers at Colorado State University and su-

perconductivity experts with Du Pont's Central Research & Development Department are collaborating to investigate the production of high-temperature superconductor (HTSC) materials by electrochemical modification of specially prepared electrodes (RP8060-7).

Superconductivity in the perovskite-type oxides, a common class of HTSC materials, is extremely sensitive to composition, particularly small variations in oxygen content. The amount of oxygen in HTSC compounds is typically controlled through high-temperature, high-pressure oxygen treatments, which are costly and difficult to control precisely. Electrochemical reaction methods offer the ability to regulate oxygen content at ordinary temperatures and pressures, thus providing an attractive alternative for superconductor fabrication.

EPRI-funded researchers are studying $La_2CuO_{4+\delta}$, a well-characterized HTSC material, to determine optimal parameters for electrochemically adjusting its oxygen content. HTSC pellets fashioned into bulk electrodes and exposed to various electrolytic processes have been tested for oxygen-change efficacy and superconductivity characteristics. For these electrodes, however, complete oxygen adjustment throughout the bulk of the material was found to require weeks of electrochemical treatment. Current research focuses on the preparation of high-quality $La_2CuO_{4+\delta}$ thin-film electrodes for which the oxygen content might be changed in minutes.

Figure 3 For many reactions, an electrochemical cell can be used to continuously regenerate a reagent or catalyst, as shown here. Such regeneration is particularly desirable when costly reagents are involved, but in many cases electrode fouling prevents its practical application. In exploratory studies, EPRI researchers have identified possible electrochemical regeneration mechanisms as well as novel electrode coatings that can reduce or prevent fouling.



As a result of these efforts, future experiments are planned involving more-complex HTSC materials. Researchers eventually hope to devise electrochemical procedures for producing micropatterned HTSC devices for specific electrical applications.

Other electrochemistry research

A number of other electrosynthesis projects have been funded by the NSF under the joint research initiative. They include an exploration of the factors controlling chirality in electrosynthesis, a fundamental study of electron transfer reactions involving organic compounds, and work to develop a novel sacrificial electrode process for producing fluorinated compounds and other organic products.

Important new understanding and control of the factors governing electrochemical synthesis are now being achieved through EPRI-NSF collaboration, with several process improvements and practical applications showing promise. To further advance the scientific knowledge and ultimate commercial prospects of electrosynthesis, EPRI and the NSF expect to sponsor an electrochemistry conference, to periodically fund promising new projects, and to increasingly draw the chemical industry into collaboration in an area that holds the potential for important benefits for chemistry as well as electricity.

Using Chemical Translators for Water Quality Permitting

by Robert Brocksen, Environment & Health Business Unit

The electric utility industry, like many other industries and many municipalities, must adhere to discharge limits for toxic pollutants such as metals. These limits are specified in National Pollutant Discharge Elimination System (NPDES) permits. Traditionally, numerical NPDES limits have been set by using criteria developed under a specific set of conditions that were then applied nationally. Over time, regulators have come to accept the idea that this approach is too rigid and that site-specific, water-quality-based permit limits provide a more accurate assessment of toxicological effects in receiving waters. Consequently, as NPDES permits for toxic pollutants come due for renewal, many utilities find themselves concerned with water-quality-based permitting for the first time.

Regulatory background

The U.S. Environmental Protection Agency and the states have long stipulated that NPDES permit limits for metals be expressed as total recoverable concentrations. (The total recoverable concentration is the total amount measurable—i.e., almost all of a given metal in a water sample.) The EPA has relied on the following as justification for this position:

- Interpretation of the regulations addressing permit limits for metals—40 CFR 122.45(c)—as requiring their expression in total recoverable concentrations
- The assertion that total recoverable metal serves as a conservative parameter for ambient waters and is the only metal form that can be used to reliably compute the resulting total metal concentrations in both the water column and the sediments (58 Fed Reg 32132)
- The need to be conservative in protecting receiving waters

However, in related regulatory activity—the development of ambient water quality criteria—the EPA and several states (Virginia, Texas, and Maryland) have concluded that the criteria should be expressed as bioavailable or dissolved concentrations, rather than total recoverable concentrations. Section 304(a)(1) of the Clean Water Act requires the EPA to publish and periodically update ambient water quality criteria for the protection of aquatic life on the basis of the latest scientific knowledge. Federal criteria are published as guidance to the state regulatory authorities, which then set enforceable ambient water quality criteria for individual water bodies.

With respect to water quality standards, the EPA's 1992 National Toxics Rule states that "the water quality criteria are not threshold values. One should not expect that once these values are exceeded, the result is a measurable impact on aquatic life. The aquatic life criteria embody conservative assumptions so that small excursions above criteria will not result in adverse impact. The data indicate that if ambient water quality criteria are met, organisms in the receiving water are protected from adverse impacts" (57 Fed Reg 60876). Similarly, two EPA documents—*Technical Support Document for Water Quality-Based Toxics Control* (EPA report 505/2-90-001) and *Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria* (October 1993)—explicitly encourage greater flexibility in the implementation of aquatic life criteria for metals.

Metals toxicity criteria and chemical translators

Metals exist in natural waters in a variety of dissolved and particulate forms. The bioavailability and toxicity of a metal are highly dependent on the physical and chemical forms of the metal. It is widely accepted

ABSTRACT *In 1994 EPRI published the* Chemical Translator Guidance Manual, *which provides utility environmental managers with a methodology for translating a water quality criterion for such toxic pollutants as metals—expressed as either a dissolved concentration or a bioavailable concentration—into a National Pollutant Discharge Elimination System permit limit, expressed as a total recoverable concentration. This methodology is particularly useful because it allows unique, site-specific receiving-water characteristics to be taken into account in calculating permit limits. The Environmental Protection Agency is considering using EPRI's* Chemical Translator Guidance Manual *as the basis for its own guidance document, to be issued in 1995.*

that dissolved metals are generally more toxic to aquatic life than are particulate-bound metals. However, recent research has demonstrated that even the dissolved-metal concentration in ambient waters may overstate bioavailability and toxicity. In laboratory studies, many inorganically and organically bound complexes that are measured in a metal's dissolved fraction (i.e., the metal that passes through a filter of a certain size) have relatively low bioavailability. For example, dissolved copper includes such relatively nonbioavailable and nontoxic forms as humic and fulvic acid colloids, many inorganic copper complexes (i.e., carbonates), and most organic copper complexes.

Ambient water quality criteria for most metals were developed from acute (1-hour average concentration) and chronic (4-day average concentration) toxicity data collected in laboratory studies. These studies typically used highly soluble metal salts dissolved in laboratory dilution water to estimate the toxicity of a given metal. Since laboratory dilution water has low suspended solids and low organic carbon concentration, its metal-binding capacity is lower than that of most ambient waters. As a result, criteria derived from laboratory studies do not accurately reflect the fate and behavior of metals in natural receiving waters and are likely to overestimate the toxicity of metals in ambient waters.

The policy and guidance memorandum issued by the EPA Office of Water in 1993 summarized the problems associated with accurately determining water quality criteria for metals and concluded the following:

- Dissolved concentrations are better indicators of the bioavailable fraction of metal than are total recoverable concentrations.
- State water quality standards should be based on dissolved metal.
- A translator can be used to calculate total recoverable permit limits from dissolved water quality criteria.

The general equation for using a chemical translator to calculate an NPDES permit limit (i.e., a total recoverable amount) from a dissolved-concentration water quality criterion is as follows: the permit limit equals the water quality criterion times the translator times a dilution factor. At present, the EPA suggests three methods for making this conversion:

- Use EPA-determined partition coefficients and historical data on concentrations of total suspended solids in the receiving water.
- Use a conservative conversion factor of 1.0, which makes the dissolved concentration equal to the total recoverable concentration.
- Collect receiving-water samples and determine site-specific partition coefficients for each metal.

The last two approaches are recommended. Because of concerns about the quality of the national database used to derive partition coefficients, the EPA views the first approach as an interim measure until sufficient data are available to implement either of the other approaches.

EPRI chemical translator manual

For electric utilities, the important consequences of the EPA's consideration of water-quality-based standards are that the agency now recommends that state water quality standards be implemented as dissolved-metal concentrations and says that using a chemical translator is a scientifically valid approach to determining total recoverable permit limits. The trend to use dissolved concentrations for ambient water quality standards—which was initiated by the EPA and the states of Virginia, Texas, and Maryland—is likely to continue as more states review their permitting standards.

To help utilities negotiate for the inclusion of translators in state regulations and permitting guidance and to help them develop and apply translators in NPDES permitting, EPRI developed the *Chemical Translator Guidance Manual* (TR-104047). The manual discusses alternative approaches for developing translators, which are described below. It also offers detailed information on designing site-specific studies for translators—including parameter selection, sampling design (sampling locations, number of samples, scheduling, and other conditions), sample collection, laboratory analysis, and data analysis. Field protocols for utility environmental managers to follow in designing studies for specific permit applications are provided.

It is important for users of the manual to remember that the material is generic. Specific refinements for individual applications may thus be necessary.

Developing translators: four alternatives

The first alternative for developing a chemical translator—the use of partitioning equations—can be applied to streams, rivers, lakes, and estuaries. It is not applicable to oceans, since no partitioning equations or coefficients have been developed for this type of receiving water.

For rivers, streams, and lakes (freshwater receiving waters), the equation for calculating a chemical translator, C_T/C_d, is

$$C_T/C_d = 1 + (k_{po} \cdot \{SS\}^{a+1})$$

where C_T is the total concentration of the toxicant in the water column (µg/L); C_d is the dissolved concentration of the toxicant in the water column (µg/L); k_{po} and a are constants; and $\{SS\}$ is the concentration of particulates in the water column, commonly measured as total suspended solids, or TSS (mg/L).

A chemical translator can be calculated for any freshwater effluent or receiving water by using this equation together with EPA-derived partition coefficient constants, TSS calculations provided in the guidance manual, and a site-specific suspended solids concentration. The guidance manual also contains constants applicable to estuaries that can be used in the chemical translator equation.

Texas and Maryland have adopted forms of this methodology in their regulations. As mentioned above, the EPA has expressed concern about the quality of partition coefficient values derived from the national database. Its recommendation is that the national coefficients be used as an interim measure until site-specific partition coefficients can be derived.

The advantages of this alternative are that it is very simple to apply and is very inexpensive, especially if TSS data are available. Its disadvantages are that the EPA coefficients are applicable only to fresh water and that the use of coefficients for waters

other than the ones for which they were developed may be questioned by regulators.

The second alternative, the next most straightforward approach to developing a chemical translator, is to analytically determine the total recoverable and dissolved concentrations of the metal in question and then to calculate the translator directly from these data. This approach is relatively simple to implement and provides valid chemical translators for site-specific applications.

The approach is based on the calculation of the ratio of total metal to dissolved metal in site water using a series of samples. Virginia has developed guidance for this approach that incorporates specific requirements for sampling and statistical analysis of the data. The EPRI guidance manual contains a somewhat less complex version of this alternative.

The alternative's advantages are that it is a relatively simple concept, is relatively inexpensive to implement, and is applicable to all types of receiving waters. Its major disadvantage is that when concentrations are below or near normal detection levels, translators cannot be calculated reliably without relying on more-expensive ultralow or unconventional analytical techniques.

The third alternative involves the use of site-specific partitioning equations. Site-specific regression equations can be developed to predict total metal concentrations from TSS and dissolved-metal concentrations (or to predict dissolved-metal concentrations from TSS and total metal concentrations). In this alternative, site-specific samples are collected and analyzed for TSS, total recoverable metal, and dissolved metal. Samples should be collected from the effluent, the receiving water before mixing with the effluent, the receiving water at the edge of the mixing zone, and/or the far-field receiving water. If concentrations are low, then so-called clean sampling techniques and ultralow metal analysis techniques may be required.

Data analysis for this technique consists of a multiple regression of total metal concentration on dissolved-metal concentration and TSS. The multiple regression can be used in two ways to calculate permit limits. First, the dissolved water quality standard and a selected TSS value can be used to directly calculate a total concentration value. Second, the regression equation can be incorporated in the permit and used to calculate a sample-specific compliance limit every time an effluent monitoring sample is collected. For example, TSS and total metal would be measured in the effluent sample. The total metal effluent limit would be calculated from the dissolved-metal criterion and the measured TSS concentration. The total metal concentration measured in the sample would then be compared with the calculated limit to see if the limit had been exceeded.

The greatest advantage of this alternative is its site-specificity, which the EPA views favorably. Also, because it relates the translator to TSS levels in the effluent and the receiving waters, this approach may increase the degree of flexibility in permit monitoring or in the defense of enforcement actions. For instance, high total metal concentrations in the effluent may be related to high TSS in the effluent without any increase in dissolved or bioavailable metal. The major disadvantages of this alternative are that it is more complex and expensive than the two previous ones.

It is arguable that the first three alternatives, which are all based on the determination of a ratio between total and dissolved metals, are overly conservative because not all the dissolved species of a metal may be bioavailable. Research has shown that the most bioavailable forms of metals are the free metal ions and the hydroxides. For this reason, the EPA specifically allows the use of the equilibrium model MINTEQA2 in water-quality-based permitting. A description of this model is included in the EPRI guidance manual. The model predicts speciation for many metals, given site-specific water quality conditions. Application of MINTEQA2 is limited only by the availability of input data and the geochemical knowledge of the modeler.

The primary advantage of this alternative is that it allows for a sensitivity analysis of different water quality conditions. However, at the present time there are no regulatory protocols or precedents for the use of this procedure. Also, data on the toxicity of individual metal species are limited. This alternative is therefore difficult for regulators to accept.

To sum up

The careful application of a chemical translator by utilities can increase allowable discharge limits and thereby reduce operating costs by factoring site-specific water quality conditions into permit limits. If a translator is accepted by the permitting agency, utilities can use the translator (along with a dilution factor) to calculate more-realistic but still-conservative permit limits from water quality criteria.

The EPA is considering using EPRI's *Chemical Translator Guidance Manual* in preparing its own guidance document, which is planned for release this spring. Meanwhile, EPRI is addressing the subject of biological translators, which are developed through bioassays of the effluent and/or the receiving waters, and plans to produce a biological translator guidance manual this year.

New Contracts

Project	Funding / Duration	Contractor / EPRI Project Manager
Customer Systems		
ROCS Billing System Enhancements (RP2568-35)	$100,000 13 months	Southern Electric International / L. Carmichael
Microfiltration Verification Project (RP2662-71)	$62,000 11 months	Energy and Environmental Solutions / K. Carns
Quantification of Environmental Benefits of Demand-Side Management and Electrotechnologies (RP3121-12)	$120,100 8 months	Regional Economic Research / P. Sioshansi
Indoor Air Quality/Cool Storage/Ventilation Air Preconditioning System (RP3526-7)	$196,300 12 months	Calmac Manufacturing Corp. / M. Khattar
Tests of Chlorine-Free, Low-Global-Warming-Potential Refrigerants (RP3526-9)	$70,200 12 months	Foster-Miller / M. Khattar
Energy Efficiency Improvements to the Bio-Oxidizer at the Chambersburg Hospital Demonstration Site (RP3742-1)	$292,600 7 months	Bio-Oxidation / M. Jones
Application of Ultraviolet Germicidal Irradiation for Air Disinfection (RP3742-3)	$75,000 9 months	Lighting Research Institute / M. Jones
Ozonation of Cooling Water (RP3761-2)	$645,700 24 months	Minnesota Power / M. Jones
Commercial End-Use Load Data Development (RP3819-20)	$90,000 4 months	RLW Analytics / R. Gilliam
EPRI Partnership for Industrial Competitiveness: Plant Surveys for Printing and Printed Circuit Boards (RP3829-15)	$240,000 13 months	Chem Systems / W. Smith
Vertimill Pilot Plant Study, Taconite Grinding (RP3866-1)	$420,000 24 months	University of Minnesota / E. Eckhart
Metals, Glass, and Minerals Production (RP3866-2)	$150,000 12 months	Carnegie Mellon University / E. Eckhart
High-Efficiency Laundry Project (RP3872-2)	$1,624,300 36 months	Maytag Co. / J. Kesselring
Pinch Energy Optimization Study (RP3879-6)	$83,500 9 months	Simons Engineering / A. Amarnath
Pinch Energy Optimization Study (RP3879-7)	$74,800 9 months	Simons Engineering / A. Amarnath
Microwave Processing of Thin-Sheet Materials (RP3899-1)	$1,222,900 47 months	IBM Corp. / E. Eckhart
Customer Heating System Choice Modeling (RP3904-2)	$119,600 10 months	Freeman, Sullivan & Co. / P. Meagher
Residential Scoping Study: Customer Loyalty and Its Relationship to Service, Quality, and Value (RP4001-19)	$182,500 3 months	PNR & Associates / T. Henneberger
Generation		
Development and Delivery of CQE 1.0 (RP1400-31)	$782,600 21 months	Black & Veatch / D. O'Connor
Research and Development of Proton-Conducting Fuel Cell (RP1676-20)	$150,000 24 months	Russian Federal Nuclear Center / R. Goldstein
Gasification of Waste Tires (RP2190-10)	$80,000 2 months	Centerior Energy Corp. / E. Hughes
Handbook on Rewinding Medium-Voltage Motor (RP2308-34)	$95,600 9 months	Jarsco Engineering Corp. / J. Stein
Rapid-Mix Burner Oil Development Program (RP2869-23)	$69,500 1 month	Radian Corp. / A. Facchiano
CG-DAMS Enhancements (RP2917-51)	$60,000 8 months	Anatech Research Corp. / D. Morris
Catalytic Ceramic Filter for Removal of SO_2, NO_x, and Fly Ash (RP3004-42)	$75,000 6 months	Ceramem Corp. / R. Chang
Siemens V84.2/V94.2 Combustion Turbine Life Management System (RP3064-4)	$733,600 37 months	PowerGen / G. Touchton
Assessment of Impacts of NO_x Reduction Technologies on Ash Use (RP3176-17)	$75,000 3 months	Radian Corp. / D. Golden
Simulator Acceptance Testing and Training Program Development Guidelines (RP3384-23)	$155,400 13 months	Entor Corp. / R. Fray
Economic Development Through Biomass Systems Integration (RP3407-28)	$76,000 10 months	Kansas Electric Utilities Research Program / J. Turnbull
Air Heater Seal Leakage Improvement Demonstration (RP3455-3)	$271,000 7 months	TU Electric / J. Bickley
On-Line Feedpump Expert System (RP3478-2)	$378,000 17 months	Bogan / R. Colsher
Demonstration of Automation Concepts at Lewis Creek and Nelson Stations of Gulf States Utilities (RP3690-3)	$118,900 9 months	Leeds & Northrup Co. / D. Broske
Wind Turbine Performance Verification (RP3691-1)	$4,380,000 77 months	Green Mountain Power Co. / E. Davis
Erosion Characteristics of Dam Foundations (RP3752-1)	$638,000 40 months	U.S. Bureau of the Interior / D. Morris
Bench-Scale Testing for a Landfill Gas Cleanup System (RP3755-3)	$69,500 12 months	University of Southern California / D. Herman
Preparation and Combustion Facility for Coal-Water-Slurry Fuel: Feasibility Study (RP3852-4)	$83,000 5 months	Energy and Environmental Research Corp. / W. Weber
Maintenance Benchmarking at Generating Plants of San Diego Gas & Electric (RP3854-4)	$75,000 5 months	HSB Reliability Technologies / D. Broske
Advanced Condition-Monitoring System for Hydroelectric Generators (RP3857-5)	$281,000 33 months	MCM Enterprise / J. Stein
Advanced Condition-Monitoring System for Hydroelectric Generators (RP3857-6)	$281,000 33 months	Iris Power Engineering / J. Stein
Distributed X.500 Directory Services (RP3867-2)	$174,000 13 months	Southern Company Services / G. Pfiasterer
Steam Treatment for Zebra Mussels (RP3894-4)	$205,200 7 months	Stone & Webster Engineering Corp. / J. Tsou
Chlorine Dioxide Treatment of Zebra Mussels at Alma Generating Station (RP3894-5)	$63,100 11 months	Dairyland Power Cooperative / J. Tsou
Modified 9Cr-1Mo (P91) Steel Characterization of Service-Aged Materials and Weldments (RP3911-1)	$1,283,800 56 months	PowerGen PLC / W. Bakker
On-Line Performance Monitor (RP3922-1)	$166,500 12 months	Bridger Scientific / J. Tsou
Improved Performance Instrumentation (RP3925-1)	$195,000 9 months	Pacific Gas and Electric Co. / J. Weiss
Evaluation of REACH NO_x Reduction Technology for Oil Firing (RP3956-1)	$676,000 13 months	Orange & Rockland / A. Facchiano
Integrated Hydro Diagnostics System (RP3971-1)	$310,900 9 months	British Columbia Hydro & Power Authority / J. Birk
Solutions for Low Dissolved Oxygen at Hydro Sites (RP3972-1)	$129,400 19 months	Aquatic Systems Engineering / D. Morris
Ceramics for Gas Turbines (RP3979-1)	$1,185,400 36 months	General Electric Co. / W. Bakker

Project	Funding/ Duration	Contractor/EPRI Project Manager
Nuclear Power		
10 CFR 54 Implementation Guidelines (RP3075-14)	$121,000 9 months	MDC-Ogden Environmental and Energy Services Co./ *J. Carey*
Analysis and Confirmation of Robust Performance for the Flow-Diversion Barrier System Within the Yucca Mountain Site (RP3294-17)	$99,900 14 months	Intera Sciences/ *J. Kessler*
Baltimore Gas and Electric's Life Extension Activities at Calvert Cliffs Nuclear Plant (RP3343-19)	$59,100 4 months	Bechtel Group/ *J. Carey*
BWR Feedwater Iron Reduction (RP3388-11)	$128,000 12 months	GPU Nuclear Corp./ *P. Millett*
Demonstration of an Advanced Resin-Cleaning System (RP3388-12)	$680,800 7 months	Entergy Operations/ *P. Millett*
Implementation of a Lattice Physics Method Using Arbitrary Geometry Modeling Techniques (RP3418-4)	$122,700 26 months	TransWare Enterprises/ *J. Chao*
Iodine Chemistry in Containment (RP3425-3)	$294,900 24 months	Ontario Hydro/ *M. Merilo*
Reactivity Insertion Accidents: Scoping Study (RP3574-8)	$119,000 4 months	S. Levy/ *L. Agee*
Radiation Monitoring System Maintenance Guide (RP3814-12)	$71,800 9 months	Louisiana Laissez-Faire/ *C. Price*
Feedwater Instrumentation and Control Maintenance Guide (RP3814-13)	$79,100 9 months	Edan Engineering Corp./ *R. Wolfgang*
CE Reactor Protection System and Plant Protection System Obsolescence and Maintainability (RP3943-1)	$435,300 15 months	ABB Combustion Engineering/ *C. Wilkinson*
Hatch-1 In-Reactor Testing (RPC101-30)	$250,000 28 months	Georgia Power Co./ *K. Ramp*
Influence of Irradiation and Stress/Strain on the In-Reactor Behavior of High-Purity Stainless Steels and Nickel-Base Alloys (RPC103-11)	$1,808,600 60 months	Siemens/ *J. Nelson*
Qualification and Demonstration of 5-AP for Secondary-System pH Control (RPS416-11)	$179,500 11 months	CENTEC-21/ *P. Millett*
Demonstration of AC Potential Drop Techniques for Detecting Small Cracks in Steam Generator Tubing at High Temperature (RPS511-6)	$50,000 16 months	Massachusetts Institute of Technology/ *A. McIlree*
Power Delivery		
Using Real-Time-Pricing Data for Service Design and Analysis (RP2801-9)	$90,000 24 months	Rutgers University/ *R. Siddiqi*
Power Electronic Building Blocks for Affordable High Performance of Electric Power (RP3115-5)	$4,000,000 52 months	Harris Corp./ *B. Damsky*
Demonstration of a Power Plant–Control Center Communication Link at Consolidated Edison (RP3555-9)	$273,300 7 months	ESCA Corp /*D. Becker*
Quantified Subsequent Lightning Strokes Study (RP3669-3)	$376,600 48 months	State University of New York Research Foundation/ *R. Bernstein*
Demonstration of EPRI Operator Training Simulator as a Distribution System Simulator (RP3731-4)	$228,100 10 months	National Systems & Research Co./ *G. Cauley*
Technologies for Inspecting Transmission Lines (RP3873-2)	$87,000 5 months	Radian Corp./ *P. Lyons*
Demonstration of Advanced T&D Construction Technology (RP3942-1)	$330,300 4 months	Underground Research/ *R. Samm*
IS-POW DYNAMICS, Version 4 (RP3950-1)	$80,000 2 months	Decision Focus/ *R. Schainker*
Performance-Based Monitoring and Control for Increased Operational Efficiency of Power Systems (RP3954-1)	$500,000 36 months	Massachusetts Institute of Technology/ *R. Adapa*
Development of UCA Applications for Europe (RP3961-1)	$338,000 11 months	Kema/ *W. Blair*
UCA Advanced Broadband Communications (RP3969-1)	$339,800 12 months	Houston Lighting & Power Co./ *J. Melcher*
UCA/DAIS Demonstration (RP3977-1)	$2,085,200 15 months	Pacific Gas and Electric Co./ *W. Blair*
Integrated Standardized Database for Resource Planning (RP7443-1)	$95,100 3 months	Abacus Programming Corp./ *L. Rubin*
Transmission-Comprehensive Marginal Costing Project (RP7802-7)	$235,000 16 months	Laurits R. Christensen Associates/ *R. Siddiqi*
Strategic Development		
Landfill Disposal of Creosote- and PCP-Treated Wood Poles (RP2879-36)	$121,700 12 months	University of Pittsburgh/ *I. Murarka*
Feasibility of Conducting an Epidemiologic Investigation of Children Living in VHCC (Very High Current Configuration) Dwellings (RP2964-28)	$98,500 12 months	Radian Corp./ *K. Ebi*
Lymphatic Leukemia in Mice Exposed to 60-Hz Magnetic Fields (RP2965-31)	$1,439,700 34 months	BACRA/ *C. Rafferty*
Melatonin Levels in Continuous Magnetic Fields (RP3349-10)	$300,000 12 months	Midwest Research Institute/ *R. Kavet*
Power System Control Valuation Methodology (RP3436-9)	$74,600 7 months	General Electric Co./ *V. Longo*
Utility Greenhouse Gas Decision Tools (RP3441-20)	$100,300 5 months	Decision Focus/ *T. Wilson*
Regional-Scale Watershed Modeling Under Conditions of Change (RP3802-2)	$50,000 60 months	U.S. Interior Department/ *D. McIntosh*
Substation Magnetic Field Management (RP3959-1)	$365,100 24 months	Ohio State University/ *R. Lordan*
Magnetic Field Management Research at the High-Voltage Transmission Research Center (RP3959-2)	$849,900 24 months	General Electric Co./ *R. Lordan*
EMF Field Exposure Reduction Supply Curves (RP3959-6)	$88,900 4 months	Carnegie Mellon University/ *R. Lordan*
Genetic Optimization of Neural Network Architectures for Power Industry Problems, Phase 2 (RP8016-6)	$283,800 36 months	Honeywell/ *A. Wildberger*
IEA Greenhouse Gas R&D Program (RP8020-6)	$150,000 37 months	British Coal Corp./ *R. Rhudy*
Thermophilic Conversion of Synthesis Gas to Hydrogen and Fuel Oxygenates (RP8021-8)	$251,600 24 months	Bioengineering Resources/ *S. Yunker*
Fuzzy Adaptive Control of Fossil Fuel Power Plants (RP8030-16)	$100,000 34 months	Georgia Tech Research Corp./ *M. Perakis*
Stability and Control of Intelligent Vehicle/Highway Systems (RP8030-18)	$100,000 16 months	Princeton University/ *J. Weiss*
Qualitative Design and Verification of Heterogeneous Controllers (RP8030-21)	$58,000 19 months	University of Texas, Austin/ *S. Bhatt*
Feedback Control Approach to Gain Scheduling (RP8030-23)	$112,500 31 months	University of Texas, Austin/ *J. Weiss*
Optical pH Sensors for High-Temperature Environments (RP8031-1)	$78,400 7 months	Research International/ *B. Syrett*
Photoinhibition of Localized Corrosion (RP8041-7)	$200,000 22 months	Pennsylvania State University/ *B. Syrett*
Diamond Synthesis at Atmospheric Pressure (RP8042-5)	$120,000 20 months	Stanford University/ *J. Stringer*
Mechanical Deformation Effects on Magnetic Properties (RP8046-6)	$85,000 11 months	Southwest Research Institute/ *R. Tilley*
Novel Solid-Oxide Ion Electrolyte (RP8062-8)	$122,200 24 months	University of Texas, Austin/ *W. Bakker*
Single-Component Oxide Fuel Cell Operating at 600–800°C (RP8062-9)	$149,400 6 months	University of Pennsylvania/ *R. Goldstein*
Proton-Conducting Fuel Cell (RP8062-10)	$50,000 24 months	Russian Federal Nuclear Center/ *R. Goldstein*
Test Burn of Mixtures of Contaminated Soil and Coal and of Coal Tar and Coal in a Cyclone Boiler (RP9015-16)	$275,100 10 months	Remediation Technologies/ *I. Murarka*
SCION (Southern Consortium Intermediate Oxidant Network) Support (RP9031-6)	$101,300 27 months	Environmental Science & Engineering/ *A. Hansen*
SARMAP Modeling System Aerosol and Visibility Augmentation (RP9052-3)	$285,000 4 months	Pacific Gas and Electric Co./ *A. Hansen*

New Technical Reports

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

CUSTOMER SYSTEMS

Designing Profitable Rate Options Using Area- and Time-Specific Costs: Central Power and Light Company (TC3629 Project Results)
TR-104375 Final Report (RP3629-1); $200
Contractor: Energy and Environmental Economics
Business Unit: Marketing Tools & DSM
EPRI Project Manager: G. Heffner

Information Agenda for Competitive Utilities
TR-104448 Final Report (RP3085-12); $200
Contractor: Venture Associates (a unit of Arthur Andersen LLP)
Business Unit: Marketing Tools & DSM
EPRI Project Manager: P. Sioshansi

Survey of Innovative Rates: 1994 Update
TR-104491 Final Report (RP2343-11); $200
Contractor: CSA Energy Consultants, Inc.
Business Unit: Marketing Tools & DSM
EPRI Project Manager: P. Sioshansi

GENERATION

Tuning Guidelines for Utility Fossil Plant Process Control, Vol. 2
TR-102052-V2 Final Report (RP2710-17); $10,000
Contractors: HEI Engineers; Northern States Power Co.
Business Unit: Fossil Power Plants
EPRI Project Manager: J. Weiss

Guidelines for Specification and Procurement of Large-Screen Projection Displays in Control Rooms
TR-102710 Final Report (RP3152-25); $10,000
Contractors: Entor Corp.; MITRE Corp.
Business Unit: Fossil Power Plants
EPRI Project Manager: R. Fray

Guidelines for the Design and Installation of By-Product Containment Facilities
TR-103322 Final Report (RP1457-7); $10,000
Contractor: Baker Environmental, Inc.
Business Unit: Environmental Control
EPRI Project Manager: M. McLearn

Development of Turbomachinery Trains for the CASHING, NGCASH, and IGCASH Cycle Applications
TR-103348 Final Report (RP2620-10); $200
Contractors: Westinghouse Electric Corp.; Energy Storage and Power Consultants, Inc.
Business Unit: Advanced Fossil Power Systems
EPRI Project Manager: A. Cohn

Simulator Procurement Guidelines for Fossil Power Plants
TR-103790 Final Report (RP3152-1); $10,000
Contractor: General Physics Corp.
Business Unit: Fossil Power Plants
EPRI Project Manager: R. Fray

Tire-Derived-Fuel Cofiring Test in a Pulverized-Coal Utility Boiler
TR-103851 Final Report (RP2190-8); $200
Business Unit: Renewables, Storage & Hydro
EPRI Project Manager: C. McGowin

Organic and Inorganic Hazardous Waste Stabilization Using Coal Combustion By-Product Materials
TR-103958 Final Report (RP3176-3); $200
Contractor: Western Research Institute
Business Unit: Environmental Control
EPRI Project Manager: D. Golden

Distributed Resources Assessment in the Service Territory of Anza Electric Cooperative
TR-104153 Final Report (RP1677-27); license required
Contractor: Rumla, Inc.
Business Unit: Advanced Fossil Power Systems
EPRI Project Manager: D. Rastler

Evaluation of Nonmagnetic Generator Retaining Rings
TR-104209 Final Report (RP2719-1, RP3232-1); $10,000
Business Units: Fossil Power Plants; Nuclear Power
EPRI Project Managers: J. Stein, J. Lance

Planning Your First Wind Power Project: A Primer for Utilities
TR-104398 Final Report (RP3404-12); $200
Contractor: RLA Consulting
Business Unit: Renewables, Storage & Hydro
EPRI Project Manager: E. Davis

Proceedings: 11th International Symposium on Use and Management of Coal Combustion By-Products, Vols. 1 and 2
TR-104657-V1, TR-104657-V2 Proceedings (RP3176); $595 for set
Contractor: American Coal Ash Association
Business Unit: Environmental Control
EPRI Project Manager: D. Golden

NUCLEAR POWER

Guidelines for Electromagnetic Interference Testing in Power Plants
TR-102323 Final Report (RP2409-20, -23, -26, -51; RP4242-1); $1000
Contractors: Public Service Electric and Gas Co.; CHAR Services, Inc.; EPRI Nondestructive Evaluation Center
Business Unit: Nuclear Power
EPRI Project Managers: R. James, C. Lin

Piping and Fitting Dynamic Reliability Program, Vols. 1–5
TR-102792-V1–V5 Final Report (RP1543-15); $1000
Contractor: General Electric Co.
Business Unit: Nuclear Power
EPRI Project Manager: S. Gosselin

Advanced Amine Application Guidelines, Revision 1
TR-102952-R1 Final Report (RP2977-5); $1000
Contractor: GEBCO Engineering, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: P. Millett

Neutron Radiation Embrittlement and Microstructural Characterization of Ferritic Steels (Joint EPRI-CRIEPI RPV Embrittlement Studies)
TR-103173 Final Report (RP2975-5); license required
Contractor: Westinghouse Science & Technology Center
Business Unit: Nuclear Power
EPRI Project Managers: R. Carter, T. Griesbach

Procedures Software Tool (PST) Requirements Analysis and Functional Description (Joint EPRI-CRIEPI Human Factors Studies)
TR-103247 Final Report (RP3111-3); license required
Contractor: Battelle Human Affairs Research Centers
Business Unit: Nuclear Power
EPRI Project Managers: J. Yasutake, L. Hanes

Maintenance Productivity Aids for Reactor Coolant and Recirculation Pump Seal Maintenance (Joint EPRI-CRIEPI Human Factors Studies)
TR-103356 Final Report (RP3111-4); license required
Contractor: Westinghouse Science & Technology Center
Business Unit: Nuclear Power
EPRI Project Managers: J. Yasutake, L. Hanes

Advanced Technology Training System (ATTS) for Motor-Operated Valve Maintenance
TR-103368 Final Report (RP3111-78); license required
Contractor: Galaxy Scientific Corp.
Business Unit: Nuclear Power
EPRI Project Manager: J. Yasutake

Programmable Logic Controller Requirements and Evaluation Guidelines for BWRs
TR-103734 Final Report (RP3406-5); $20,000
Contractor: S. Levy Inc.
Business Unit: Nuclear Power
EPRI Project Manager: J. Naser

PWR Containment Structures License Renewal Industry Report, Revision 1
TR-103835 Final Report (RP2643-33); $200
Contractor: Bechtel Power Corp.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

BWR Reactor Pressure Vessel License Renewal Industry Report, Revision 1
TR-103836 Final Report (RP2643-33); $200
Contractor: General Electric Co.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

PWR Reactor Pressure Vessel License Renewal Industry Report, Revision 1
TR-103837 Final Report (RP2643-33); $200
Contractors: Failure Analysis Associates; ABB Combustion Engineering; Applied Science and Technology
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

PWR Reactor Pressure Vessel Internals License Renewal Industry Report, Revision 1
TR-103838 Final Report (RP2643-32); $200
Contractors: Westinghouse Electric Co.; Duke Power Co.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

BWR Reactor Pressure Vessel Internals License Renewal Industry Report, Revision 1
TR-103839 Final Report (RP2643-33); $200
Contractor: General Electric Co.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

BWR Containments License Renewal Industry Report, Revision 1
TR-103840 Final Report (RP2643-30); $200
Contractor: MDC-Ogden Environmental and Energy Services Co., Inc.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

Low-Voltage Environmentally-Qualified Cable License Renewal Industry Report, Revision 1
TR-103841 Final Report (RP2643-33); $200
Contractors: Sandia National Laboratories, Star, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

Class 1 Structures License Renewal Industry Report, Revision 1
TR-103842 Final Report (RP2643-27); $200
Contractor: Bechtel Power Corp.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

BWR Primary Coolant Pressure Boundary License Renewal Industry Report, Revision 1
TR-103843 Final Report (RP2643-33); $200
Contractor: General Electric Co.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

PWR Reactor Coolant System License Renewal Industry Report, Revision 1
TR-103844 Final Report (RP2643-32); $200
Contractors: B&W Nuclear Technologies; Duke Power Co.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey

Job Cards for Pump and Valve Maintenance, Vol. 1: Development and Evaluation (Joint EPRI-CRIEPI Human Factors Studies)
TR-103951-V1 Final Report (RP3111-5); license required
Contractor: Anacapa Sciences, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: L. Hanes

Job Cards for Pump and Valve Maintenance, Vol. 2: Feasibility of Industrywide Implementation (Joint EPRI-CRIEPI Human Factors Studies)
TR-103951-V2 Final Report (RP3111-5); license required
Contractor: Anacapa Sciences, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: L. Hanes

Wrong Unit, Train, and Component Events at U.S. Nuclear Power Plants (Joint EPRI-CRIEPI Human Factors Studies)
TR-103954 Final Report (RP3111-8); license required
Contractor: RCG/Hagler Bailly, Inc.
Business Unit: Nuclear Power
EPRI Project Managers: J. Ketchel, L. Hanes

Nuclear Power Plant Applications of Bar Codes and Other Automatic Identification Technologies (Joint EPRI-CRIEPI Human Factors Studies)
TR-103955 Final Report (RP3111-36); license required
Contractors: ENCORE Technical Resources, Inc.; INS, Inc.; Basic Technology Corp.
Business Unit: Nuclear Power
EPRI Project Managers: J. Ketchel, L. Hanes

Microstructural Characterization of Alloy 718
TR-103970 Final Report (RP3154-7); $20,000
Contractor: Westinghouse Science and Technology
Business Unit: Nuclear Power
EPRI Project Manager: J. Nelson

Plant Communications and Computing Architecture Plan Methodology, Vols. 1 and 2
TR-104129-V1, TR-104129-V2 Final Report (RP3373-9); $100,000 for set
Contractors: Queue Systems, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: D. Wilkinson

A Survey of the Effect of Primary Coolant pH on Westinghouse PWR Plant Radiation Fields
TR-104180 Final Report (RP2493-5); $200
Contractor: Nuclear Electric PLC
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken

Prototype Compact Computer Aid for Maintenance (Joint EPRI-CRIEPI Human Factors Studies)
TR-104323 Final Report (RP3111-5); license required
Contractor: Anacapa Sciences, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: L. Hanes

EPRI-CRIEPI Joint Human Factors Program Summary Report
TR-104324 Final Report (RP3111-10); license required
Contractor: Parsons and Associates
Business Unit: Nuclear Power
EPRI Project Manager: L. Hanes

Residual Stress Analysis of Alloy 600 U-Bends, Reverse U-Bends, and C-Rings
TR-104340 Final Report (RPS406-3); $200
Contractor: Materials Research Laboratory, Pennsylvania State University
Business Unit: Nuclear Power
EPRI Project Manager: A. McIlree

Hydrogen Water Chemistry Effects on BWR Radiation Buildup, Vol. 1: Laboratory Results and Plant Data
TR-104605-V1 Final Report (RP3313-1), $200
Contractor: GE Nuclear Energy
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken

Evaluation of Recent Experience Using Zinc Addition to Reduce BWR Primary System Radiation Buildup
TR-104606 Interim Report (RP2758-1, RP3419-1), $5000
Contractor: GE Nuclear Energy
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken

Borated Stainless Steel Joining Technology
TR-104627 Final Report (RP3290-4), $200
Contractor: Analytical Resources Inc./Engineering Resources, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: R. Lambert

Fuel Surveillance Through Condenser Changeout at the Hatch 1 and Hatch 2 Reactors
TR-104702 Final Report (RP2946-4); license required
Contractor: GE Nuclear Energy
Business Unit: Nuclear Power
EPRI Project Manager: B. Cheng

Evaluation of Fuel Rod Leakage Mechanisms: Summary Report (Joint EPRI-ESEERCO-Westinghouse Studies)
TR-104721 Final Report (RP2229-1); $20,000
Contractor: Westinghouse Electric Corp.
Business Unit: Nuclear Power
EPRI Project Manager: B. Cheng

Advanced Technology Training System (ATTS) for Motor-Operated Valve Training and ATTS Authoring System (Joint EPRI-CRIEPI Human Factors Studies)
TR-104746 Final Report (RP3111-78); license required
Contractor: Galaxy Scientific Corp.
Business Unit: Nuclear Power
EPRI Project Manager: L. Hanes

Skin Injuries From Discrete Radioactive Particles: A Summary of EPRI-Sponsored Experiments
TR-104781 Final Report (RP3099-9); $200
Contractors: Texas A&M University; ENCORE Technical Resources, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook

POWER DELIVERY

Monte Carlo Approach for Estimating Contingency Statistics, Vols. 1 and 2
TR-103639-V1, TR-103639-V2 Final Report (RP3159-1); $5000 for set
Contractors: Texas A&M University; Public Service Electric and Gas Co.
Business Unit: Power System Operations
EPRI Project Managers: M. Lauby, R. Adapa

Electrical Performance of a Portable Protective Gap (PPG) in a Compact 550-kV Tower
TR-103860 Final Report (RP2472-6); $5000
Contractor: General Electric Co.
Business Unit: Transmission
EPRI Project Managers: J. Hall, P. Lyons

Air Gap Sparkover and Gap Factors: Analysis of Published Data
TR-104437 Final Report (RP3787); $5000
Contractor: General Electric Co.
Business Unit: Transmission
EPRI Project Managers: J. Hall, P. Lyons

Considerations for Measuring Wind Loads on Overhead Transmission Line Conductors in Field Conditions
TR-104478 Final Report (RP3478); $5000
Contractor: Sverdrup Technology—TLMRC
Business Unit: Transmission
EPRI Project Manager: P. Lyons

Evaluation of the Results of Several Full-Scale Conductor Wind Loading Experiments
TR-104479 Final Report (RP3478); $5000
Contractor: Sverdrup Technology—TLMRC
Business Unit: Transmission
EPRI Project Manager: P. Lyons

DC Multi-Infeed Study
TR-104586 Final Report (RP2675-4, -5); $5000
Contractors: Centro de Pesquisas de Energia Elétrica (CEPEL); University of Wisconsin
Business Unit: Power System Operations
EPRI Project Managers: S. Nilsson, A. Edris

Case History Evaluation of the Behavior of Drilled Shafts Under Axial and Lateral Loading
TR-104601 Final Report (RP1493-4); $5000
Contractor: Cornell University
Business Unit: Transmission
EPRI Project Manager: A. Hirany

STRATEGIC DEVELOPMENT

Revegetation of Flue Gas Desulfurization Sludge Pond Disposal Sites
TR-103312 Interim Report (RP2485-29); $200
Contractor: University of Arizona
Business Unit: Environment & Health
EPRI Project Manager: J. Goodrich-Mahoney

Remediation Strategies for Source Materials and Contaminated Media at Manufactured Gas Plant (MGP) Sites
TR-103811 Final Report (RP2879-6); $200
Contractor: Remediation Technologies, Inc.
Business Unit: Environment & Health
EPRI Project Manager: I. Murarka

Nonlinear Control-Oriented Boiler Modeling: A Benchmark for Controller Design
TR-103941 Final Report (RP8010-19); $200
Contractor: Mechanical and Industrial Engineering Department, University of Illinois
Business Unit: Strategic R&D
EPRI Project Manager: S. Bhatt

Stabilizing Predictive Control Algorithm for Regulation and Tracking
TR-103942 Final Report (RP8010-19); $200
Contractor: Mechanical and Industrial Engineering Department, University of Illinois
Business Unit: Strategic R&D
EPRI Project Managers: S. Bhatt, M. Wildberger

Laser Surface Melting and Alloying of Type 304L Stainless Steel: Improvement of Corrosion and Wear Properties
TR-104322 Final Report (RP2426-39); $200
Contractor: New Mexico Institute of Mining and Technology
Business Unit: Strategic R&D
EPRI Project Manager: B. Syrett

The EMDEX Project: Residential Study, Vols. 1–3
TR-104325-V1–V3 Final Report (RP2966-1); $200 each volume
Contractor: T. Dan Bracken, Inc.
Business Unit: Environment & Health
EPRI Project Manager: R. Takemoto-Hambleton

Economic Impacts of Carbon Taxes: Overview
TR-104430-V1 Final Report (RP3441-1); $200
Contractors: Charles River Associates; DRI/McGraw-Hill
Business Unit: Environment & Health
EPRI Project Manager: L. Williams

Economic Impacts of Carbon Taxes: Detailed Results
TR-104430-V2 Final Report (RP3441-1); $200
Contractors: Charles River Associates; DRI/McGraw-Hill
Business Unit: Environment & Health
EPRI Project Manager: L. Williams

Photo Inhibition of Localized Corrosion
TR-104565 Final Report (RP8002-36); $200
Contractor: Pennsylvania State University
Business Unit: Strategic R&D
EPRI Project Manager: B. Syrett

Proceedings: Welding and Repair Technology for Fossil Power Plants—1994 EPRI International Conference
TR-104588 Proceedings (RP8046-4, RP2481-1); $1000
Contractor: EPRI Repair & Replacement Applications Center
Business Unit: Strategic R&D
EPRI Project Manager: R. Viswanathan

Electric Utility Trace Substances Synthesis Report, Vols. 1–4
TR-104614-V1–V4 (RP3081, RP3508, RP3237, RP3177, RP3453); $1000 for set
Business Unit: Environment & Health
EPRI Project Managers: L. Levin, W. Chow, R. Chang

EPRI Events

MAY

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

8–10
13th International Conference on Fluidized-Bed Combustion
Orlando, Florida
Contact: Ellen Petrill, (415) 855-8939

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

8–12
Transmission Line Foundations
Binghamton, New York
Contact: Denise O'Toole, (415) 855-2259

10–12
Seminar on Resource Planning in a Competitive Environment
Minneapolis, Minnesota
Contact: Lynn Stone, (214) 556-6529

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

25
Risk Analysis of Surface Water Quality and Thermal Issues
Irving, Texas
Contact: Bob Goldstein, (415) 855-2593

JUNE

1–2
Analysis of Regional Ozone and Visibility Issues in a Risk Framework
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

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

7–9
3d Joint GRI/EPRI Seminar on Manufactured Gas Plant Issues
Chicago, Illinois
Contact: Ishwar Murarka, (415) 855-2150

12–14
2d International Conference on Arsenic Exposure and Health Effects
San Diego, California
Contact: Janice Yager, (415) 855-2724

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

18–21
Technology Delivery Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

19–21
CHECWORKS Users Group Meeting and International Symposium on Flow-Accelerated Corrosion
Toronto, Canada
Contact: Susan Bisetti, (415) 855-7919

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

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

26–27
Integrated Resource Planning: From Regulatory to Business-Driven Strategies
Dallas, Texas
Contact: Pam Turner, (415) 855-2010

26–27
Pricing in the 1990s: Meeting Challenges and Creating Opportunities in a Competitive Environment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

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

JULY

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

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

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

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

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

AUGUST

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

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

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

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

28–29
Polymer Technology Workshop
Palo Alto, California
Contact: Bruce Bernstein, (202) 293-7511

29–31
Distributed Resources
Kansas City, Missouri
Contact: Connie Smyser, (415) 855-2396

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

SEPTEMBER

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

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

27–29
Feedwater Heater Technology Symposium
Kansas City, Missouri
Contact: Linda Nelson, (415) 855-2127

27–29
Forecasting in a More Competitive Environment
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

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

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

OCTOBER

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

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

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

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

NOVEMBER

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

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

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

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

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

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

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