Electric and Magnetic Field Research

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

JANUARY/FEBRUARY
1990

Also in this issue • *Superconductor Applications* • *Watershed Liming* • *Genetic Ecology*

EPRI JOURNAL is published eight times each year (January/February, March, April/May, June, July/August, September, October/November and December) by the Electric Power Research Institute.

EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

EPRI JOURNAL Staff and Contributors
Brent Barker, Editor in Chief
David Dietnch, Editor
Ralph Whitaker, Feature Editor
Taylor Moore, Senior Feature Writer
David Boutacoff, Feature Writer
Mary Ann Garneau, Senior Production Editor
Eugene Robinson, Technical Editor
Jean Smith, Staff Assistant

Richard G. Claeys, Director
Corporate Communications Division

Graphics Consultant: Frank A. Rodriquez

Address correspondence to:
Editor in Chief
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

Please include the code number on your mailing label with correspondence concerning subscriptions.

Cover: Individuals encounter many magnetic fields of various strengths in the course of a typical day. Research is investigating the patterns of exposure people actually receive and whether such fields may have an effect on human health.

EDITORIAL

EMF Research: A Commitment to Excellence

EPRI has sponsored research into possible health effects from electric and magnetic fields (EMF) since the early 1970s, when attention focused on the electric fields generated around high-voltage electrical facilities. Health concerns about electric fields are now viewed as minor, a consensus partly based on results from this early EPRI-sponsored work. But more-recent studies have suggested a possible link between magnetic fields and cancer.

In light of these concerns, EPRI's EMF research was expanded and reoriented over the last several years to focus on magnetic fields. Since then, we have helped catalyze a much broader effort involving research-sponsoring organizations beyond the electric utility industry. In 1989, our program accounted for about $6 million of a $15-million-a-year (and growing) worldwide effort involving government agencies, academic research scientists, and utilities in a dozen countries.

EPRI is committed to finding the facts about health effects from EMF exposure. Our research is done by independent scientists and consultants at major laboratories and universities, including Battelle/Pacific Northwest Laboratories, Johns Hopkins University, Columbia University, Yale University, the University of Southern California, Carnegie-Mellon University, and the University of North Carolina. These researchers, many of them preeminent experts in their fields, are encouraged to publish results in the peer-reviewed scientific literature and are free to make their own interpretations of their results when and where they choose. All results have been presented at the annual public review of EMF research sponsored by EPRI and the Department of Energy. To further ensure the objectivity of the research, EPRI's program is guided by an independent scientific advisory panel composed of some of the nation's top experts in life sciences and public health.

The broad range of EPRI's health studies, focusing largely on epidemiology and laboratory science, has been designed to significantly reduce the uncertainties about EMF and health over the next four years. If additional research is then needed, we will redirect and target the work as appropriate. But because EPRI's program also encompasses a substantial effort in exposure assessment—including exposure hardware, analytical software, EMF measurement surveys, and laboratory structures—we will also be much better informed about EMF exposures and about methods of reducing them, if that is necessary.

Time will tell. At EPRI we are committed to taking the time, sponsoring first-class research with investigators of the highest integrity and credentials, and objectively reporting the results to the public and our utility members.

George M. Hidy, Vice President
Environment Division

RESEARCH UPDATE

36 **Concrete Gravity Dam Stability**

Research is providing utilities with the data collection methods and modeling tools they need to respond to more-stringent federal dam stability analysis requirements.

38 **Application of Genetic Ecology to Bioremediation**

Promising research results support the hypothesis that the manipulation of environmental factors can affect the abundance and functioning of genes, and that biotechnologies based on this concept could be developed for in situ waste cleanup.

41 **National Electrical Code Revision**

Recently approved code provisions allowing smaller service entrances and main distribution panels in new restaurants can result in significant first-cost savings that improve the market position of all-electric facilities.

44 **NCIG Update**

Through the five-year-old organization NCIG, EPRI and several of its member utilities collaborate in research and technology transfer efforts that address technical issues related to nuclear power plant physical facilities.

46 **Automated Distribution**

Automated distribution systems using expert systems technology can make operating decisions, coordinate components, issue commands, and provide real-time operating data; two full-scale system demonstrations are under way.

28 Watershed Liming

DEPARTMENTS

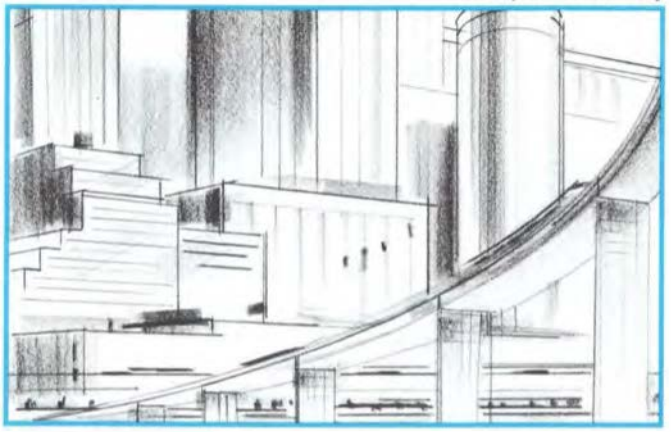
34 **Tech Transfer News**
49 **New Contracts**
50 **New Technical Reports**
51 **New Computer Software**
52 **Calendar**
53 **Authors and Articles**
54 **Index to 1989**

EPRI JOURNAL

Volume 15, Number 1 January/February 1990

4 EMF

18 Superconductivity



EDITORIAL

EMF Research:
A Commitment to Excellence

COVER STORY

4 Pursuing the Science of EMF
The results of new, carefully designed studies of possible health risks from electric and magnetic fields are expected to significantly reduce the uncertainties on this issue in the next several years.

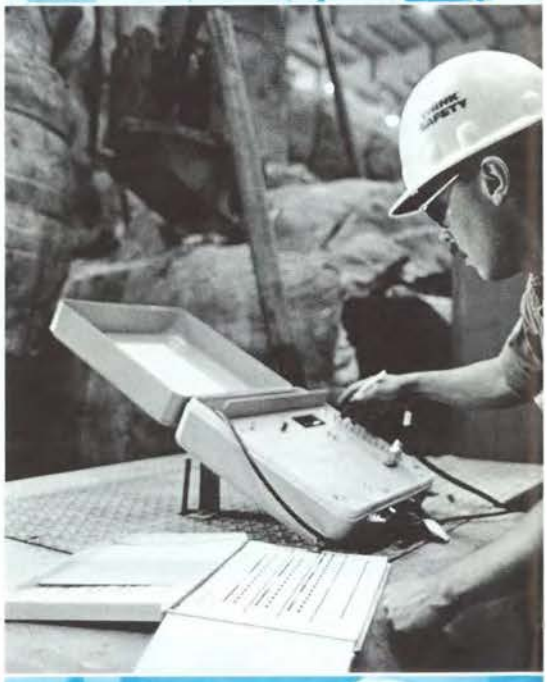
FEATURES

18 Superconductivity: Dealing in Futures
If the present technical limitations of high-temperature superconductors yield to further research, these revolutionary materials could have applications that affect virtually every aspect of modern life.

28 Working With the Watershed
With lake liming established as an effective method of neutralizing acidified lakes, researchers are investigating whether adding limestone to watershed soils will provide a broader and longer-lasting benefit.

PURSUING THE SCIENCE OF EMF

Research on electric and magnetic fields and their possible effects on human health is entering a period of intense scrutiny. A new battery of carefully designed studies being sponsored by EPRI and other organizations is expected to significantly narrow uncertainties about such health risks in the next few years. Studies of workers in so-called electrical occupations will be particularly important in this research.



At laboratories and research centers in about a dozen countries, an estimated $15 million a year is being spent to investigate whether electric or magnetic fields—such as those associated with power lines, common house wiring, or appliances—pose a health risk. Sponsorship of EMF studies has recently expanded to include a variety of previously uninvolved parties—the National Cancer Institute in the United States, Sweden's National Institute of Occupational Health, France's Electricité de France, several Canadian utilities, and the World Health Organization.

The ramp-up in international research mirrors a growing public concern that has been given a sharp edge of urgency by recent coverage in the popular media. While the tone is certainly more subdued in the technical literature, changes in viewpoint regarding EMF are also cropping up among members of the research community.

The new perspective is reflected in a paper issued last June by Congress's Office of Technology Assessment and prepared by Indira Nair, Granger Morgan, and Keith Florig of Carnegie-Mellon University's Department of Engineering and Public Policy. According to the OTA report, recent epidemiologic studies, although controversial and far from conclusive, are beginning to provide a basis for concern about risks from chronic exposure to EMF: "As recently as a few years ago, scientists were making categorical statements that on the basis of all available evidence there are no health risks from human exposure to power-frequency fields," the authors state. "In our view, the emerging evidence no longer allows one to categorically assert that there are no risks. But it does not provide a basis for asserting that there is a significant risk."

The careful qualification is understandable. The studies referred to in the OTA paper have suggested that magnetic fields may cause serious health effects—specifically, that they may promote cancer—and that they may have other effects, such as the alteration of circadian (internal biological) rhythms. For every study that has found evidence of a specific effect, however, there are others that have shown no effect. Still, as the report implies, there has been a sufficient accumulation of positive findings to warrant broadening the scientific inquiry.

"It is extremely important for EPRI to continue vigorously pursuing the scientific and engineering questions on behalf of the electric utility industry," says Dr. Leonard Sagan, a physician who heads EPRI's EMF studies. "There is a great deal we still do not understand about EMF and that we must know in order to determine what, if anything, should be done. We are pursuing this knowledge through a broad research program that encompasses epidemiology, basic science, and exposure assessment."

EPRI sponsors what has been for the last several years the world's largest and most comprehensive research program in the field; at present the program comprises 30 studies that cost about $6 million a year. An advisory panel of distinguished scientists from outside the utility industry reviews and guides the EPRI research.

The emphasis of the present work is to conduct studies that eliminate as much as possible the limitations that have clouded the results of much past research. "The methodologies used in many of the epidemiologic studies have been more suitable for generating hypotheses than for testing them," says Leeka Kheifets, an epidemiologist who manages several EPRI-sponsored studies. "What is needed are studies designed to test hypotheses, along with better response rates in both cases and controls among study populations, and better, more-quantitative exposure assessment methods."

Rigorous studies are generally characterized by large sample sizes, a prospective rather than retrospective database, and carefully designed analysis of confounding factors, such as exposure to cigarette smoke or to other known carcinogens. The need for better exposure assessment in epidemiologic studies is particularly acute. Almost all past studies have used approximations or surrogates, such as the configuration of house wiring, to represent levels of exposure to magnetic fields.

According to Dr. Gilbert Omenn, dean of the School of Public Health and Community Medicine at the University of Washington and head of EPRI's independent advisory panel, "the kinds of studies now under way, including those on better methods for measuring what people are actually exposed to, offer good prospects that scientists and the public will have much better information with which to evaluate the question of EMF health risks within three years or so. Today, I think the risk is highly uncertain."

Expanding the epidemiologic database

EPRI has several key investigations in progress to narrow the uncertainties in the epidemiologic knowledge base. In the area of residential EMF exposure, a study by the University of Southern California in Los Angeles is testing the hypothesis of an EMF association with childhood leukemia. Directed by Dr. John Peters, the study involves 230 case-control pairs. Exposure assessments include 24-hour magnetic field measurements, engineering-based classification of nearby outdoor utility lines, and an extensive effort to collect information on potential confounding factors. Preliminary results are expected this spring.

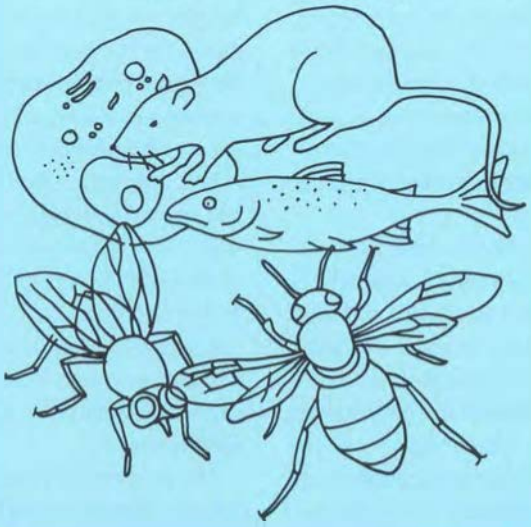
Kheifets says, "It's important to understand why a 1987 study by Dr. David Savitz found a weaker association of childhood cancer and actual measured magnetic fields in the same data that revealed an association with a surrogate exposure, which was determined by wire code classification. This is one factor the USC team is investigating.

The Spectrum of EMF Health Research

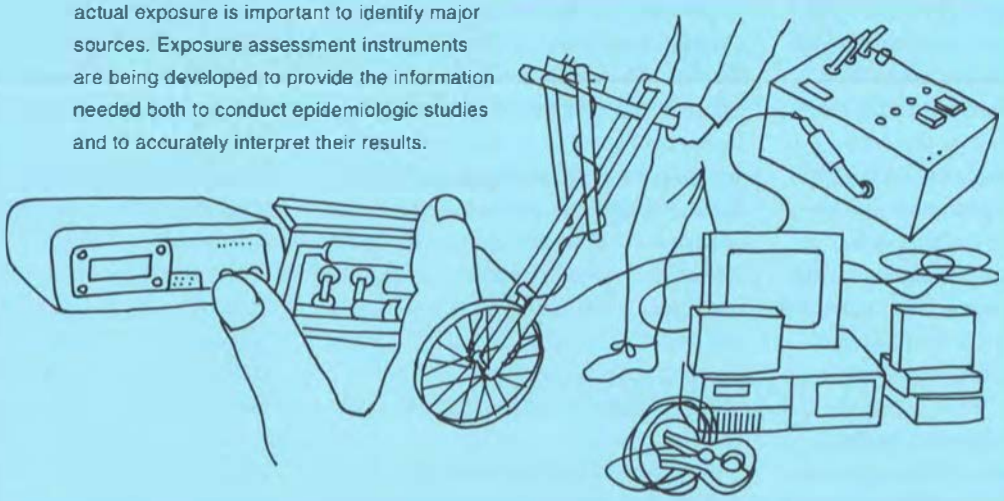
Different types of studies have different strengths and weaknesses. No one type can give the whole answer—all three are necessary to determine if there are health risks from EMF.

Epidemiology These studies are based on real people, but information, especially on exposure, is often incomplete. Occupational studies offer somewhat better exposure data than other types. Prospective studies, which follow individuals in real time, give better information than retrospective studies but take much longer. Conclusions from epidemiologic studies should be drawn only when multiple studies conducted on a variety of populations give consistent results.

Laboratory studies Such studies of cells, tissues, and whole animals offer better control—experiments can be designed to produce graded exposures and to minimize the confounding effects of diet, genetics, and the environment. Investigators can generate and examine specific hypotheses. Laboratory studies are better for establishing dose-response relationships than epidemiologic studies, and they provide the opportunity to identify which aspects of exposure are biologically important. A limitation of animal studies, however, is the difficulty of extrapolating observations to estimates of risk for humans.



Exposure assessment Measurement of actual exposure is important to identify major sources. Exposure assessment instruments are being developed to provide the information needed both to conduct epidemiologic studies and to accurately interpret their results.



"The results of the USC study will by no means be definitive, but they will provide more-precise information that will complement and improve on previous childhood cancer studies. We are using a different location and a larger number of leukemia cases, and we're hoping for a much better response rate among cases and controls. We are concentrating on one disease, leukemia, and we are doing much more detailed exposure assessment," adds Kheifets.

EMF exposure has also been implicated in changes in reproductive outcomes. As with cancer, the evidence of effects on reproductive outcomes is fragmentary. One Swedish study observed an increased frequency of abnormal birth outcomes among the wives of workers at high-voltage switchyards. In this country, Wertheimer and Leeper report longer gestation periods and lower birth weights in babies born to users of heated water beds and electric blankets.

In New Haven, Connecticut, a Yale University medical research team under EPRI sponsorship is gearing up for the first large prospective study of pregnant women and EMF exposure. Some 4000 women who enter the Yale–New Haven Medical Center for obstetric care over the next 3–4 years will form the study group. Detailed exposure assessments will be conducted for about one-quarter of them, and the results will be used to model exposures for the rest. Those monitored will wear EPRI-developed personal EMF dosimetry devices for week-long periods at several points during their pregnancies. In addition, EMF dosimeters will be left in the homes of these women for 24-hour periods.

A research team led by Dr. Michael Bracken will look for signs of retardation of intrauterine growth and late (8–12 weeks) spontaneous abortions. "This is the first large prospective study of EMF and reproductive outcomes," notes Kheifets. "We are going to learn a lot about the EMF exposures of the women in this study. A pilot study found that as many as 38% of the pregnant women in a small sample used electric blankets and electrically heated water beds, which produced average exposures of 13–30 milligauss [mG], so in the full study we should be able to see the effects of those exposures if there are any."

Results should become available in 1993. That's about a year after results are expected from an EMF assessment recently added to a spontaneous abortion study being conducted by state health researchers in California. "I think these two studies, if the results are consistent, will settle the issue of whether magnetic fields affect reproductive outcomes," says Kheifets.

In occupational epidemiology, final results are expected in the next few months from the first large EPRI study. The retrospective study of former telephone workers is now winding down, having found no association between leukemia and EMF exposure and surprisingly few telephone workers who are actually exposed to significant magnetic fields on the job.

Directed by Dr. Genevieve Matanoski of Johns Hopkins University, the study analyzed the occurrence of leukemia as well as the magnetic field exposures of workers from a population of over a million former Bell System employees. Bob Black, the EPRI project manager, says detailed measurements were made for estimation of the actual EMF exposures of the leukemia cases and the controls. Other occupational risk factors—exposure to organic solvents such as benzene, for example—were also evaluated.

"We expected the EMF exposures for some jobs to be comparable to those of electric utility line workers, but that turned out not to be the case," Black explains. The only set of telephone workers who do receive significant job-related magnetic field exposures, according to Black, are cable-splicers and others who often work in urban underground vaults.

One anticipated conclusion of the study is that, because few significant magnetic field exposures were found, the apparent lack of an association between job classification and leukemia has not been conclusively demonstrated. "Still, it was a big study population, involving generally greater magnetic fields than are typical of residential environments," says Black. A more-recent follow-on study appears to have found some positive associations between occupational EMF exposure and cancer, however. (See box, p. 8.)

What should perhaps prove more persuasive is another study now in full gear—a study of electric utility workers. Five major U.S. utilities are participating in a retrospective study of some 150,000 white male employees who worked for the companies between 1950 and 1986. Within about three years, it should become clear whether workers in certain utility jobs run an increased risk of leukemia or brain cancer.

The study will cover 2.5 million person-years, says Black. "There have been only a few industrial epidemiologic studies that were bigger," he explains, citing those of rubber factory and shipyard workers. David Savitz of the University of North Carolina is directing the epidemiology. Enertech Consultants is performing extensive measurements of the EMF exposures of workers in various job classifications that will be used to reconstruct and estimate employee exposure histories. Confounding risk factors will also be analyzed.

In still another EPRI-sponsored study, careful measurements of EMF exposures of persons in certain job categories are being made. The populations from three previous studies (Seattle, Los Angeles, and New Zealand) indicating increased leukemia risk are being reanalyzed on the basis of actual EMF measurements. EPRI-developed instruments and protocols have been used to assess the exposures of about 750 workers in the three locations. The earlier studies did not measure actual exposures but instead used only job titles for classification. Re-

Telephone Workers and EMF: A Closer Look

Despite negative results in a national study of telephone workers that sought epidemiologic evidence of a link between occupational EMF exposure and cancer, preliminary results from a recent follow-on study are drawing attention because they appear to contradict the earlier findings.

Both studies were conducted by researchers at Johns Hopkins University under the direction of Dr. Genevieve Matanoski, the principal investigator. The original study, sponsored by EPRI, analyzed leukemia deaths during 1975–1980 among 1.2 million retired and active employees of the former Bell telephone system. Although more information continues to be added on the employment and exposure histories of subjects in this nationwide study (known as a case-control study), the Johns Hopkins researchers have reported finding no evidence of increased risk of leukemia among telephone linemen. This is the case when linemen—workers who are presumed to have greater-than-normal exposure to EMF—are analyzed as a group and when they are analyzed as subgroups characterized by estimated exposure.

In analyzing the results, however, Matanoski and her colleagues became concerned that the study might be missing a significant number of leukemia cases among younger, active workers. Only 40 deaths in the 20–49 age bracket were observed in the case-control study; something like 200 might be expected, given national leukemia mortality rates.

With funding from the National Institute of Environmental Health Sciences, part of the U.S. National Institutes of Health, the Johns Hopkins group tried to find the supposedly missing leukemia cases in a 50,000-person subset of active New York male telephone workers, aged 20–49, who were employed during 1976–1980. The team studied the incidence of all types of cancer at onset, rather than as a cause of death, by matching records of the workers with those of the New York Cancer Registry, one of the few such extensive state data banks.

Although the actual numbers of cancer cases found among the New York workers were small, the incidence rates for subjects with line-related jobs were higher than those for other telephone company employees. This was particularly true for cable-splicers, the most heavily exposed subgroup of line workers. Among the 4500 cable-splicers in the New York study, there were three cases of leukemia, equivalent to a rate seven times higher than that for other telephone workers. The cable-splicers also showed a statistically significant, 1.8-times-higher overall incidence of cancer when compared with other telephone workers. Still, the overall cancer rate for all line-related workers in the study was below that for all New York males.

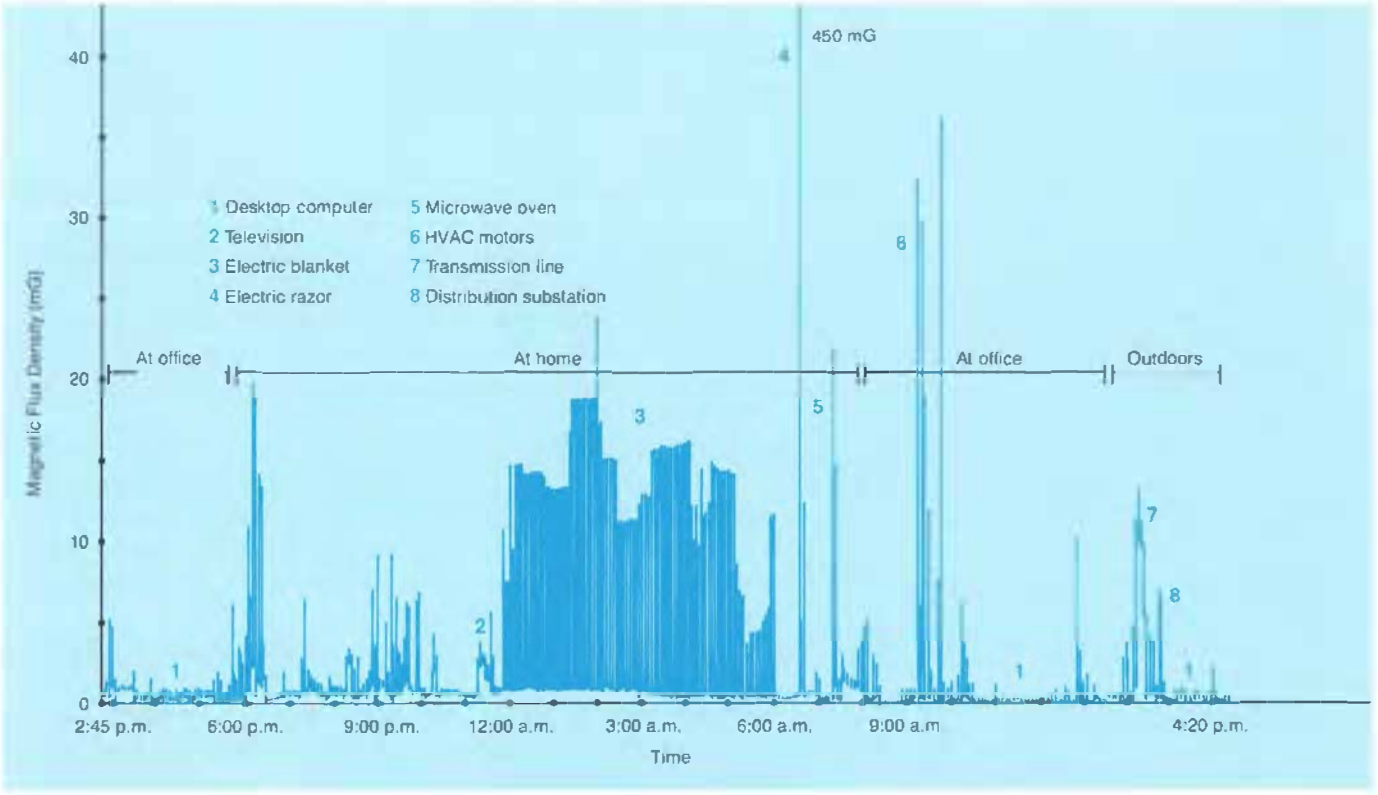
The Johns Hopkins researchers found two cases of male breast cancer in a subgroup of 9500 central office technicians, workers who were believed to be exposed to EMF primarily from older, electromechanical telephone switching systems. Zero cases of such a rare malignancy in men would ordinarily be expected. Also, compared with non–line workers, central office technicians showed a slightly higher overall rate of cancer.

In reporting these latest findings at the annual EPRI/DOE EMF contractors' research review last November, Dr. Matanoski observed that "there does appear to be an increased risk of leukemia in the young workers" and that different exposures from line work appear to result in different patterns of cancer risk. Yet she also stressed the preliminary nature of the results.

Comments EPRI's Leonard Sagan: "Because the two studies used different methodologies and involved different populations, their results are difficult to reconcile. In addition, there may be factors other than EMF exposure contributing to the incidence of cancer among the workers. From the information we have seen, however, this clearly deserves to be followed up. EPRI intends to pursue possibilities for further research in this area with Dr. Matanoski to clarify the apparent differences in results."

EMDEX Profiles Personal Exposure Through the Day

A personal magnetic exposure record taken with the EPRI-developed EMDEX device shows how the magnetic fields an individual experiences can vary through the course of a day. Periods at home show peaks from kitchen appliances and other electrical household items, including a television, an electric blanket, an electric razor, and a microwave oven. At work, fields were recorded as the subject passed building HVAC motors or worked at a desktop computer. Outdoors, the subject walked by neighborhood utility facilities, including an overhead transmission line and a distribution substation. The field levels shown are not necessarily typical of the sources indicated, but the EMDEX profile demonstrates that a great variety of sources contribute to an individual's total magnetic field exposure and that fields from such sources can vary widely.



sults of the reanalyses should be available next spring.

Laboratory studies: back to basic science

Epidemiology was the primary source of the suggested link between EMF and cancer. Ultimately, however, validation of the nature and magnitude of effects, if any, will depend both on laboratory cellular and animal studies and on epidemiologic evidence.

Ethical considerations, the difficulty in controlling genetic and environmental variables and exposure, and the length of the human lifespan together make it impossible to rely solely on human data. Besides the need to validate effects, there is a critical need to better understand the mechanisms of biological interaction. These and other questions—such as what is a useful concept of EMF dosage—are most readily answered in laboratory studies of whole animals (mostly rodents) and animal (including some human) cells and tissues.

"If there are health effects from EMF exposure, then the process has to begin at some primary level, such as macromolecules or the cell membrane, where these fields interact and cause fundamental changes," says Charles Rafferty, a biophysicist who manages most of EPRI's EMF laboratory studies. "We need to be able to identify the site of interaction and the physical mechanism. Ultimately, things have to be described in terms of the macromolecular systems that make up cells and membranes—that's the mechanistic level we need to know about."

In their general conclusions about the biological effects of EMF, the Carnegie-Mellon/OTA authors summarized what is known about central nervous system effects and the possible role of EMF in promoting cancer. Whole-animal studies indicate that "subtle and complex" effects, including altered circadian rhythms, can result from the interaction of electromagnetic fields with the central nervous system, they say. The interac-

Epidemiologic Origins

Epidemiologic studies have provided the major evidence relating residential EMF exposure to childhood cancers, including leukemia, and relating occupational exposure to leukemia and brain cancer—the health effects that have attracted the most public interest as the EMF issue has evolved.

Public concern and research interest in the possible health effects of exposure to relatively intense EMF began in the early 1970s with reports from the Soviet Union of nonspecific ailments including headache and loss of libido among workers at high-voltage switchyards. But, in 1979, results of a case-control study of children in the Denver, Colorado, area by Wertheimer and Leeper focused attention on cancer and a possible link with relatively weak EMF in homes.

Wertheimer and Leeper found an elevated risk of all cancers and a twofold risk of leukemia among children who were presumed to have received greater magnetic field exposure because of their homes' proximity to power distribution or transmission lines or transformers.

On the basis of a limited set of actual measurements, the authors classified as high or low the comparative magnitudes of magnetic fields in the homes according to their nearness to presumed high-current utility lines.

The results of the study were questioned in the scientific community because of various limitations in its design and methods. These included an unvalidated surrogate for estimating exposure and a failure to take account of such potentially important confounding causes of disease as exposure to radiation or passive exposure to cigarette smoke.

At least four other case-control studies of childhood cancer have been done since the original Wertheimer-Leeper report. Two (one in England and one in Rhode Island) found no association with magnetic field exposure, while two others (one in Sweden and another in Denver, which was designed to overcome the original study's weaknesses) also indicated positive associations.

The second Denver study, sponsored by the utility-funded New York State Power Lines Project and directed by David Savitz (an epidemiologist now at the University of North Carolina), looked at a different population of children diagnosed with cancer during a later period of time. Both wire-coding classifications and actual indoor measurements were used to characterize EMF exposure.

The exposure assessments for the 1987 Savitz study are today the source of much of what is known about residential EMF levels, pending more-detailed assessments. The overall study found that children with cancer were more likely to live in the homes with the highest assumed magnetic fields (as estimated by proximity to high-current-capacity utility lines and equipment), although the association with measured magnetic fields was very weak. No association of electric fields with cancer risks was found.

In 1982, using a methodology for exposure assessment similar to the childhood study, Wertheimer and Leeper also found an association between residential wiring configurations and adult cancers (of the nervous system, uterus, and breast). The results have been questioned because the study was conducted mostly with a non-blind exposure assessment.

Some 15 occupational epidemiology studies have looked for a link between EMF and cancer. The expectation, based on the usual concept of a linear dose-response relationship, has been that any health effects should be most discernible among workers in jobs believed to entail EMF exposures much higher than those in a residential environment.

Such so-called electrical occupations have been assumed to include aluminum smelter workers; electrical equipment assemblers and repair technicians; electricians; engineers; movie projectionists; power station personnel; power and telephone line workers; streetcar and subway operators; telegraph, radio, and radar operators; and welders.

The actual exposures typical of these occupations have not, in fact, been measured previously, although current studies are substantially expanding the knowledge base. Lack of quantitative occupational exposure data up to now may be one reason the epidemiologic data are mixed. In some studies, for some job titles, the numbers of brain and central nervous system tumors and incidence of certain types of leukemia are elevated; for others, not.

tions may depend on the frequency and intensity of the field, the earth's background magnetic field, and the time and length of exposure. "How and whether these findings have public health implications remains unclear," the authors note.

Regarding cancer promotion, the authors say cellular-level experiments point to the cell membrane as at least one site of EMF interaction. The cell membrane is a known receptor for chemical cancer promoters. At the individual cell level, the membrane governs processes that are suspected of being altered by interaction with EMF, including immune response and communication among cells. In one laboratory, EMF has been shown to increase production of a cell enzyme (ornithine decarboxylase) that is essential for normal growth, although EMF does not cause the very high ODC levels that are associated with cancer promotion, according to EPRI's Rafferty.

Similarly, to the extent that EMF is involved in altered protein synthesis, in changes in immunological or hormone status, or in altered circadian metabolic patterns, the progression of a tumor initiated by some other agent might, in turn, be affected, the Carnegie-Mellon authors note. Electric fields have been shown in rats to depress the synthesis of the hormone melatonin by the pineal gland. Suppressed melatonin levels have been associated with the growth of cancer, while administration of melatonin, under certain laboratory conditions, can slow cancer growth.

The Carnegie-Mellon authors point out that, while the observations "are consistent with the hypothesis that [EMF] may play a role in cancer or tumor development, none of these constitutes proof or even necessarily a strong indication that it does."

On the basis of his knowledge of the laboratory studies, Rafferty does not see the evidence of biological effects from exposure to magnetic fields as clear and unequivocal. "I think that overstates what we know, as well as the strength of the experiments.

"The problem is that, although some good laboratories have done some well-designed experiments, there has still not been good replication among laboratories. All the positive results from all studies everywhere get thrown into the same bag, but in general, they have not been replicated or explored thoroughly," says Rafferty.

"Until there is agreement among laboratories that when you get a particular endpoint you can do the same experiment elsewhere and get equivalent results, I would not say that we have unequivocal evidence for effects at the cell or macromolecular level. Evidence for effects in animals is also inconsistent; we certainly do not have convincing evidence for harmful effects at the whole-animal level," Rafferty adds.

Rafferty agrees with the OTA paper's emphasis on the danger and the difficulty of extrapolating observed cellular phenomena to whole organisms. "Effects at the cell level don't necessarily tell us anything about how such effects might result in physiological changes in the whole animal. Animals have strong homeostatic mechanisms designed to compensate for changes at one level with another physiological change. Generally, only very strong perturbations at the cell level will produce effects that can be seen at the level of the whole organism," Rafferty notes.

Probably the most extensively studied area of biological effects in EPRI's research has been that of birth defects; investigations have been conducted on various laboratory animals, including swine and rodents. Recently concluded work at Battelle, Pacific Northwest Laboratories, involved rats exposed to electric fields and, most recently, to magnetic fields.

Both parts of the study used groups of several hundred animals under several levels of exposure. Exposure to power-frequency electric fields ranging up to 130 kV/m produced no significant effects. The findings of the latest study, involving magnetic fields of up to 10 G, were also negative.

Bob Black, the EPRI project manager, says the rat teratology studies were among the largest of their kind ever conducted. Related experiments are being done in Sweden and Canada. But on the basis of the negative Battelle results, EPRI does not anticipate major new efforts of its own in this area.

Despite epidemiologic studies and cellular-level experiments that suggest that EMF may act as a cancer promoter, so far there have been only limited laboratory studies in whole animals to test the hypothesis. EPRI has been planning a series of whole-animal and related cellular experiments that, collectively and eventually, should help answer the question.

A workshop of leading cancer researchers in the summer of 1988 provided major input to the research planning. Among the studies recommended were a chronic toxicity-carcinogenicity evaluation employing the National Toxicology Program (NTP) protocol, a skin cancer promotion study in mice, a liver cancer promotion study in rats, studies on leukemia and brain cancer in mice, an animal immune system study, a clinical study on the human immune system, a tumor growth study, a cellular study on cancer promotion, and a battery of tests for genotoxicity (although there is no evidence that EMF is capable of causing gene mutation).

Rafferty says that ideally all of the recommended studies should be completed (whether by EPRI or by other sponsors) to establish the laboratory basis for considering the question of EMF carcinogenicity in humans. Other sponsors, including Canadian government agencies and utilities, as well as the Swedish government, are funding animal experiments on skin cancer and liver cancer promotion and the cellular cancer promotion study. EPRI is following these ef-

forts and anticipates sponsoring some additional experiments.

New projects will constitute the core of EPRI's laboratory studies on cancer. "The cornerstone of the program is a study on leukemia and brain tumors in mice and rats," says Rafferty. The project will expose several thousand rodents of susceptible strains to elevated magnetic fields over their full, two-year life spans. "If EMF is involved in the development of cancer at any stage, the effect should be demonstrable in animals. This study is designed to tell us whether magnetic fields either initiate or promote cancer or function in combination with known carcinogens," adds Rafferty. Results are expected by late 1993.

EPRI is also cooperating with the National Institute of Environmental Health Sciences to develop an NTP-protocol evaluation of EMF toxicity and carcinogenicity (another of the recommended studies). In addition, immune system studies on both animals and humans are planned. A tumor growth study in mice is also anticipated.

The best-documented physiological effect of EMF in animals, according to Rafferty, is the suppression of nighttime synthesis of melatonin under exposure to electric fields. "If this observation is accurate—and we are now examining this—the possibility that EMF could affect human health through the alteration of pineal gland function must be taken seriously," he says. Various animal studies suggest that melatonin can modulate the immune system and even directly suppress the growth of cancer cells. The hormone is also associated with regulating development and reproduction and with modulating behavior and related circadian rhythms.

EPRI is sponsoring follow-up studies of published work on electric fields and melatonin synthesis and is planning an experiment to test the effect of melatonin suppression on tumor growth. Building on the results of these projects, future studies will more fully explore the human health implications of these factors and attempt to specify the thresholds of response for both electric and magnetic fields as well as the site of biological interaction. A 1988 pilot study of human volunteers using electric blankets—conducted for EPRI at Battelle—was inconclusive in identifying an effect of magnetic field exposure on melatonin synthesis.

The search for mechanisms

The epidemiologic studies suggesting an association between exposure to magnetic fields and cancer were controversial in the scientific community because, among other reasons, they had puzzling implications for the physical mechanism of biological damage. Because there is no evidence that EMF transfers energy capable of damaging gene-carrying chromosomes in cells, and because in several cell studies magnetic fields have no damaging effects on genes, EMF does not fit within the single-stage model that explains how most known carcinogens cause cancer.

A more-recent, two-stage model of cancer suggests the interaction of an initiating agent (i.e., one that does damage genes) with later exposure to a promoter agent that can stimulate abnormal growth but that cannot by itself cause cancer. EMF plausibly could play a role as a promoter under this theory of cancer. Moreover, the positive statistical associations between cancer and EMF exposure that have been found in some epidemiologic studies have encompassed several types of cancer, an observation that seems more consistent with the hypothesized role of EMF as a cancer promoter.

The biological research literature abounds with reports of EMF effects, ranging from altered calcium ion flux across cell membranes to activation of enzymes, changes in cells' immune activity, endocrine system changes, and alteration of DNA, RNA, and protein synthesis. Still, notes EPRI's Rafferty, "no mechanism of EMF interaction uniquely accounts for these effects."

Among the hypothesized mechanisms of EMF interaction are the induction by magnetic fields of currents in tissue that in some way alter cell membrane function; molecular resonances at certain frequencies of an oscillating magnetic field in combination with the earth's static magnetic field, which could affect the flow of ions across the cell membrane (the cyclotron resonance model); and the interaction of magnetic fields with magnetite bodies in nerve cell structures.

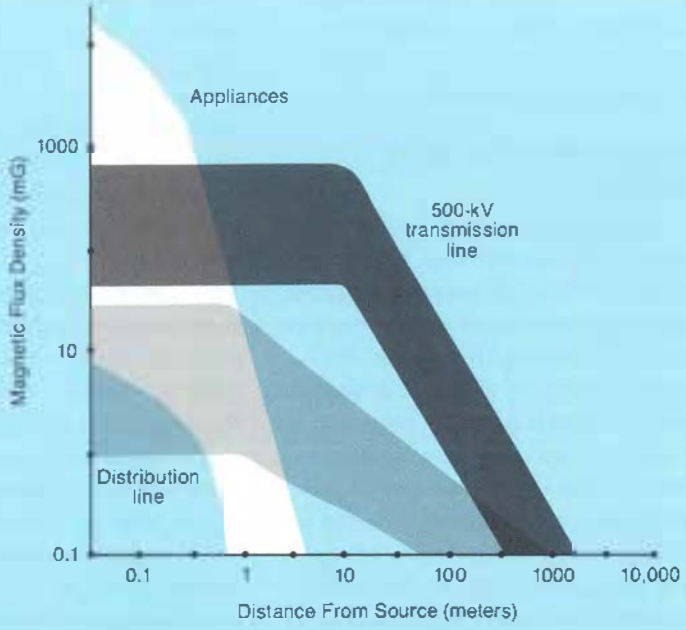
Of these theories, says Rafferty, interaction with magnetite represents the only well-defined biophysical model. It is known that bacteria containing ferromagnetic material will orient their motion along an applied magnetic field. "We don't really know how this might affect the functions of higher organisms, or even if it applies, but it's a very interesting area of research," he adds. EPRI-sponsored work at the California Institute of Technology is currently looking for a magnetic field receptor in the nerve cell structure of salmon that is believed to be related to their migration behavior.

Several key experiments that gave rise to the cyclotron resonance model, such as studies of diatom movement and of calcium flux in human lymphocytes, are being explored further, says Rafferty. He says the hypothesis is still considered highly implausible because the normal thermal energy flux in cells is several orders of magnitude greater than the very small coupled energy that may result from magnetic field resonance with ions.

Other mechanistic studies that EPRI is supporting involve the area of gene expression. Although EMF does not appear to damage DNA structure directly, it has been suggested that EMF may alter cell processes by interfering with the transcription of RNA, an intermediate step in the process by which DNA dictates protein production. EPRI-funded work at Columbia University and Hunter College is exploring the changes in RNA

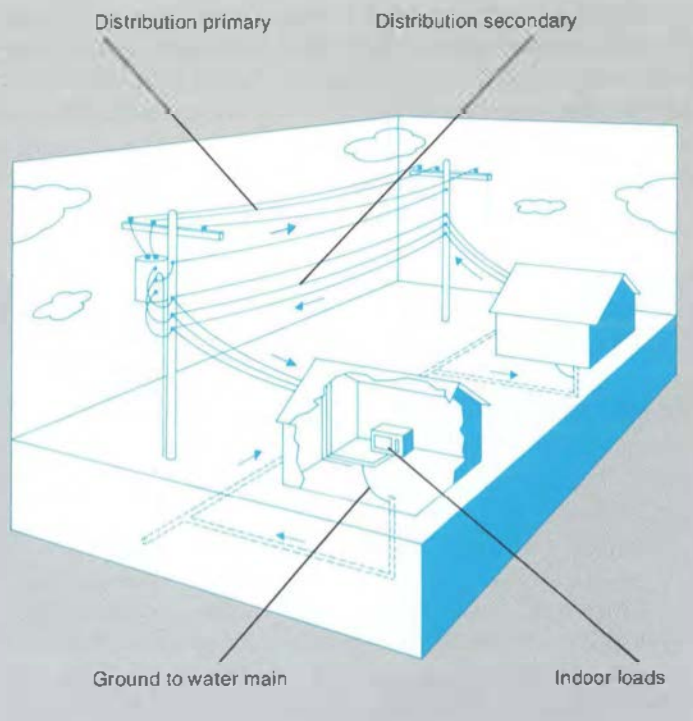
Magnetic Field Sources in Perspective

The intensity of both electric and magnetic fields diminishes with distance from the source, whether it is a utility transmission or distribution line or any of a variety of electrical home appliances. Different rates of decay of field strength with distance result from the electrical properties of the various sources. As the graph indicates, magnetic field densities at close proximity to many common electrical appliances can greatly exceed those experienced directly underneath utility power lines. But fields are generated only when devices are on, while the typically lower fields from power lines tend to be more continuous. Whether brief but intense exposures from electrical appliances are more or less biologically significant than chronic, low-level exposures is not known.



Residential Magnetic Fields: A Dynamic Environment

Key sources of magnetic fields in typical residential environments include overhead utility distribution lines (both primary and secondary circuits), the electrical grounding system (usually to the metallic water main), and indoor appliances (e.g., televisions). Possible other sources include unusual wiring configurations, underground distribution lines, and nearby high-voltage transmission lines. In the case of overhead distribution lines, magnetic fields in addition to those generated by balanced currents in the primary and secondary conductors can result from net currents—the vector sum of all the individual wire currents (arrows)—which fluctuate as loads change. And in buildings that are typically grounded to the same maze of underground water pipes, indoor fields can even be affected by return currents from loads in neighboring structures. A fully wired laboratory structure and distribution circuit similar to the arrangement in the diagram have been constructed at EPRI's High Voltage Transmission Research Center to study the EMF environment under different simulated loads and electrical conditions.



transcription and protein synthesis, using the salivary cells of flies and a variety of human cells. The Institute also closely monitors mechanism research being conducted internationally.

Getting a better handle on exposure

A major challenge in both epidemiologic and basic laboratory research, and a major part of EPRI's EMF research program, involves dosimetry and exposure assessment. Although highly variable over time and space, the electric and magnetic fields that people normally come into contact with are thought to be very weak. But it is known that around certain appliances and motors, or in the immediate vicinity of any facility or equipment that controls, carries, or uses large amounts of electricity, the fields can be several to many orders of magnitude more intense.

Getting accurate information on the strength and distribution of these fields is crucial to the soundness of study results and, more generally, to the understanding of the baseline presence of EMF in the modern environment. It is in exposure assessment that EPRI has perhaps made the most headway to date.

A powerful computer program for calculating electric and magnetic fields around high-voltage transmission lines—ENVIRO, a product of earlier EPRI EMF activity—is available as part of the TLWorkstation™ and is widely used by utilities in transmission system planning and engineering. But present research must consider a broader universe of exposure sources, including distribution lines, household wiring, and electrical appliances.

To measure fields from such sources, two new portable devices for measuring personal exposure have been commercially developed and are being used in the field. The first, EMDEX (electric and magnetic digital exposure system), is a battery-powered, microprocessor-based device worn on a beltpack for sampling and recording field levels over extended periods. It weighs about a pound and was developed for EPRI by Enertech Consultants and General Electric. Some 60 utilities have conducted EMF surveys of various utility occupational environments using EMDEX.

EMDEX is now being commercially produced under license by Electric Field Measurements of West Stockbridge, Massachusetts, at a cost of around $2000 per instrument. At a rate of up to once every second, EMDEX records the magnetic field component along three axes, electric fields, and motion in the geomagnetic field. A personal computer loaded with EMDEX's accompanying software is used to set up the instrument at the start of a survey and to receive and analyze downloaded data.

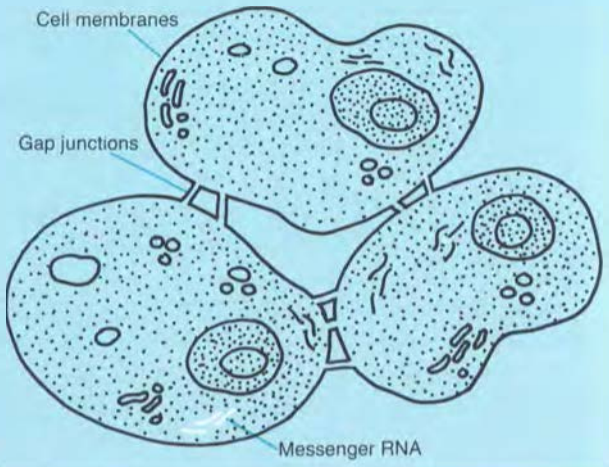
According to Stan Sussman, the EPRI project manager who has guided the development of EMDEX, the project has become a model for follow-on hardware work. "The accelerated approach to commercialization—encouraging a large number of utilities to join in a cooperative exposure assessment effort—has been invaluable in speeding parallel work on measurement protocols and in beginning the collection of measurement data as soon as possible," says Sussman.

EPRI has also sponsored the development of AMEX (average magnetic field exposure meter), a two-ounce wristwatch-style screening device. It gives a cumulative readout of a single-axis magnetic field measurement. A limited number of units have been produced for use by EPRI researchers and utilities. Made in quantity, the AMEX would cost about $100 per device.

Sussman says the near-term goals for next-generation exposure measurement hardware are to add the three-axis capability to AMEX, to reduce the cost and size of EMDEX, and to make both instruments more rugged and reliable. Proto-

The Search for Cellular Mechanisms

Various mechanisms have been proposed to explain how magnetic fields affect biological systems and thus may be involved in promoting cancer or in producing other health effects. Some theories focus on the organ or macromolecular level. According to one, for example, magnetic fields may suppress the human immune system's resistance to the initiation or progression of cancer from some other cause. This suppression could result from direct effects of magnetic fields on lymphocytes or from their altering of the body's production of a key hormone, melatonin. Other hypothesized mechanisms of magnetic field interaction extend down to the subcellular level, involving altered communication at the junctions between cells or on cellular control functions involving RNA.



Related Studies Here and Abroad

Cumulative EPRI funding for EMF research since the earliest projects began in 1973 now totals more than $25 million; the current program is investing about $6 million a year. The work is conducted by leading independent research scientists at major universities and laboratories and managed at EPRI by a team of experts in biology, epidemiology, physics, public health, and risk assessment.

EPRI's EMF research has been complemented in this country over the years by a basic sciences program sponsored by the U.S. Department of Energy, currently funded at around $3 million a year. Research programs at the state level are also under way or have been completed in California, Florida, and New York.

EPRI research managers and contractors also communicate with researchers in many of the 11 other countries with active projects on various aspects of EMF; collectively, funding for research abroad nearly equals that of the EPRI and DOE programs combined. Sweden's program is the largest, running at just under $2 million a year. Studies are also under way in Australia, Britain, Canada, Finland, France, Italy, Japan, New Zealand, Norway, and West Germany.

A study involving up to 12 countries is being coordinated by the World Health Organization's International Agency for Research on Cancer, based in Lyon, France. That project will examine over 3000 cases of childhood cancer for perturbations in postnatal immune system development. The children's residential EMF exposures will be assessed.

Two closely linked studies in Canada will be partially funded by EPRI, the Canadian Electrical Association, Ontario Hydro, and Health and Welfare Canada. The studies will be conducted by the Cancer Control Agency of British Columbia, McGill University, and the University of Toronto. Other childhood cancer studies are under way or planned in Sweden and Britain.

The National Cancer Institute is overseeing an EMF component of a study at the University of Minnesota that is investigating 2000 cases of acute lymphoblastic leukemia for various environmental exposure risks and genetic factors.

Three studies just beginning in California under the joint direction of the state Department of Health Services and the Public Utility Commission are being funded by the state's electric utilities as part of a $2-million-a-year, three-year EMF research program mandated by the legislature. One project adds an EMF exposure component to a National Institutes of Health–sponsored study at USC of childhood brain cancer.

In another of the California studies, USC and Enertech Consultants (a major EMF measurement and analysis contractor to EPRI) are repeating detailed exposure assessments in 80 Denver homes that were part of the Savitz childhood cancer study. Finally, a study in northern California of the association between water quality and the rate of spontaneous abortion in a large number of women over the next three years is being extended to include EMF exposure (based on limited measurements). Results are expected around 1992.

At about the same time, results are anticipated from an occupational study of leukemia and brain cancer among employees of the Canadian utilities Ontario Hydro and Hydro Québec and the French utility, Electricité de France. EPRI's Bob Black says the studies of U.S. and Canadian-French utility workers are on sufficiently parallel tracks that if one study begins to find positive results in a particular type of cancer or job classification, researchers for the other study can be alerted.

In Sweden, a cancer epidemiology study of utility workers has been ongoing for over a year under the direction of the country's National Institute of Occupational Health. The number of subjects being studied is substantially smaller than that in the U.S. and Canadian studies; results are due in 1991.

A second Swedish study, under the direction of Dr. Anders Ahlbom, will investigate the risk of cancer among persons who live directly under or near high-voltage transmission lines. Direct measurements of EMF exposure will be conducted within a sample of homes. This study should be completed in 1991 or 1992.

type second-generation AMEXs are anticipated around mid-1990.

Equipped with EPRI's EMF instruments and trained in measurement protocols that have been developed in parallel, utilities and EPRI contractors on various projects are sampling and logging data on the diverse EMF environment—on job sites and in homes, office buildings, schools, and other public buildings.

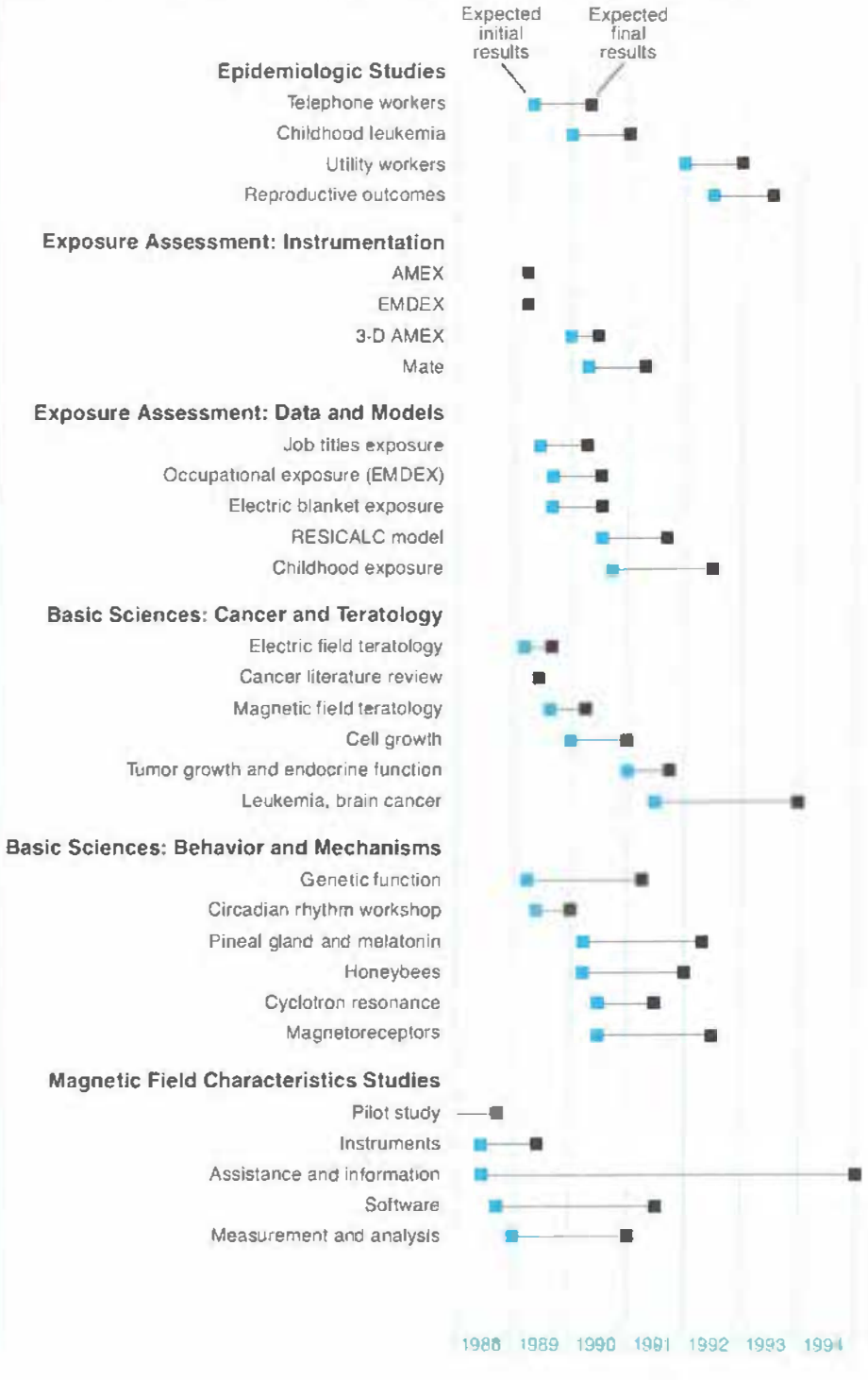
The half dozen research projects in the last few years that have measured residential magnetic fields have shown mean field flux densities of 1 mG or lower. But peak levels greater by an order of magnitude or more are also found indoors. Ongoing EPRI projects are focused on gathering a much more extensive database on residential exposure as well as developing new analytic tools for assessing them.

A laboratory residential structure and part of a neighborhood distribution system have been built at EPRI's High Voltage Transmission Research Center in Massachusetts to measure and evaluate the dynamic EMF environment under various wiring and current-loading configurations. At HVTRC, operated for EPRI by General Electric, the setup includes the fully wired laboratory house, served by a 1200-ft 23-kV overhead distribution line and with grounding connections to a specially designed water main system with variable resistance, and a number of simulated residential and primary circuit loads.

According to Greg Rauch, a project manager in EPRI's Electrical Systems Division, two types of three-axis magnetic field recorder developed primarily for utility field use will also be used at HVTRC, in the national survey, and in other related projects. One device is a waveform capture system for recording many simultaneous point measurements of fields and current flows. It will be used at the laboratory house to study, for example, how magnetic fields change as researchers vary the loads and ground resistance. Of particular interest

EPRI Projects in EMF: Timetable for Results

Some 30 EPRI-sponsored research projects spanning epidemiology, exposure assessment, and basic science are investigating various aspects of the EMF health effects question. The horizon for expected results from most major studies is within two to four years. The work is conducted in leading universities and laboratories and is guided by an independent advisory committee of distinguished scientists. EPRI also maintains close ties with other leading national and international EMF researchers.



are the fields from unbalanced return currents that can result from normal loads, from improperly grounded house wiring, and even from nearby loads outside the house.

Rauch says a second type of field recorder known as STAR (for stand-alone recorder) will also be used at the laboratory house but will be more extensively deployed in the survey now under way of residential EMF in about 1000 homes across the country. Some 25 utilities are expected to participate. A 1988 pilot study involving six member utilities and 53 homes was used to develop the measurement protocol and instrumentation. Separately, representatives of some 20 utilities were trained at an HVTRC seminar last September in the use of STAR.

Among other things, "the pilot study identified net currents and nonstandard wiring configurations as potential sources of significant indoor magnetic fields," says Rauch. (Net current is the vector sum of all currents in a system of conductors such as a three-phase distribution line.) On the other hand, a nearby high-voltage transmission line can also dominate the indoor field, he adds. The research so far indicates a wide variability in indoor field levels and in the major sources contributing to those fields.

EPRI is also sponsoring measurement surveys of a variety of nonresidential environments, including offices, public buildings, schools, and machine shops, as well as power facilities (e.g., generating plants and substations and switchyards). Most of the results of both the residential and nonresidential survey activity should be available in 1991. The Institute is also sponsoring detailed magnetic field characterization work on electric blankets at Carnegie-Mellon University. A computer program for modeling exposure to such fields is expected to be out by the middle of this year.

Many of the data being gathered from EPRI projects and other projects on residential magnetic fields (their sources, their intensities, and how they vary over time and space through a structure) are to be incorporated as they become available into a powerful new software package in the works. When it is released in about two years, the program—dubbed RESICALC—will calculate and display a map of indoor residential magnetic fields for various combinations of sources and current flows.

Now under development by Enertech, RESICALC will feature a user interface with three-dimensional CAD-type color graphics, including icons for various structural features, external and internal electrical wiring, and appliances. "It's a very ambitious software effort," says Sussman, the EPRI project manager. "Users will be able to flexibly define the dimensions and the mechanical and electrical layout of a structure and see it modeled in three dimensions on the screen. After assigning voltage and current values and specifying some time variables, they can dynamically calculate the magnetic fields and view those in three dimensions with the different intensity levels shown in color as they vary through the interior space.

"Users could also play 'what if' games and evaluate changes in the fields at different levels of power use or current flow and different numbers and locations of field sources," adds Sussman. "The ultimate design objective is to enable the user to flexibly model an individual's exposure as the person moves about the house, with the clock running, so to speak, and some or all of the sources operating. One form of output might be a graph of integrated exposure over time." RESICALC will be tested in limited release in the coming year.

The continuing search for answers

As the depth and breadth of EPRI's research program should indicate, suggestions in recent epidemiologic and laboratory studies of a link between electric and magnetic fields and risks to human health are being taken seriously. A broad effort has been mounted to investigate the issue and sort out the truth from a maze of fragmentary, vague, and sometimes contradictory observations. As the electric utility industry's science and technology organization, EPRI will remain at the center of the pursuit of the broadest base of objective scientific understanding of EMF.

EPRI and other research organizations in the United States are not alone in this pursuit of the truth about EMF health effects. Agencies and groups in some dozen countries are independently engaged in a coordinated research effort. There is reason to hope that within three to five years science will provide a much clearer understanding of three basic questions that are at the heart of EPRI's EMF research: Is there a risk to human health? What are the biologically significant exposures, if any? And how does EMF cause biological effects? ■

Further reading

Electric and Magnetic Fields: Human Health Studies. EPRI Environment Briefing. November 1989. EN.3010.11.89.

Electric and Magnetic Field Fundamentals: An EMF Health Effects Resource Paper. EPRI brochure. September 1989. EN.3012.9.89.

EMDEX (Electric and Magnetic Digital Exposure) System Manuals. Vols. 1 and 2. Report for RP799-16, prepared by Enertech Consultants, Inc. September 1989. EPRI EN-6518.

Pilot Study of Residential Power Frequency Magnetic Fields. Final report for RP2942, prepared by General Electric Co. September 1989. EPRI EL-6509.

United States Congress, Office of Technology Assessment. *Biological Effects of Power Frequency Electric and Magnetic Fields: Background Paper.* June 1989.

Carnegie-Mellon University, Department of Engineering and Public Policy. "Electric and Magnetic Fields from 60-Hz Electric Power: What Do We Know About Possible Health Risks?" 1989.

The EMDEX: Measuring Personal Exposure to Electric and Magnetic Fields. July 1989. EPRI videotape EA89-02.

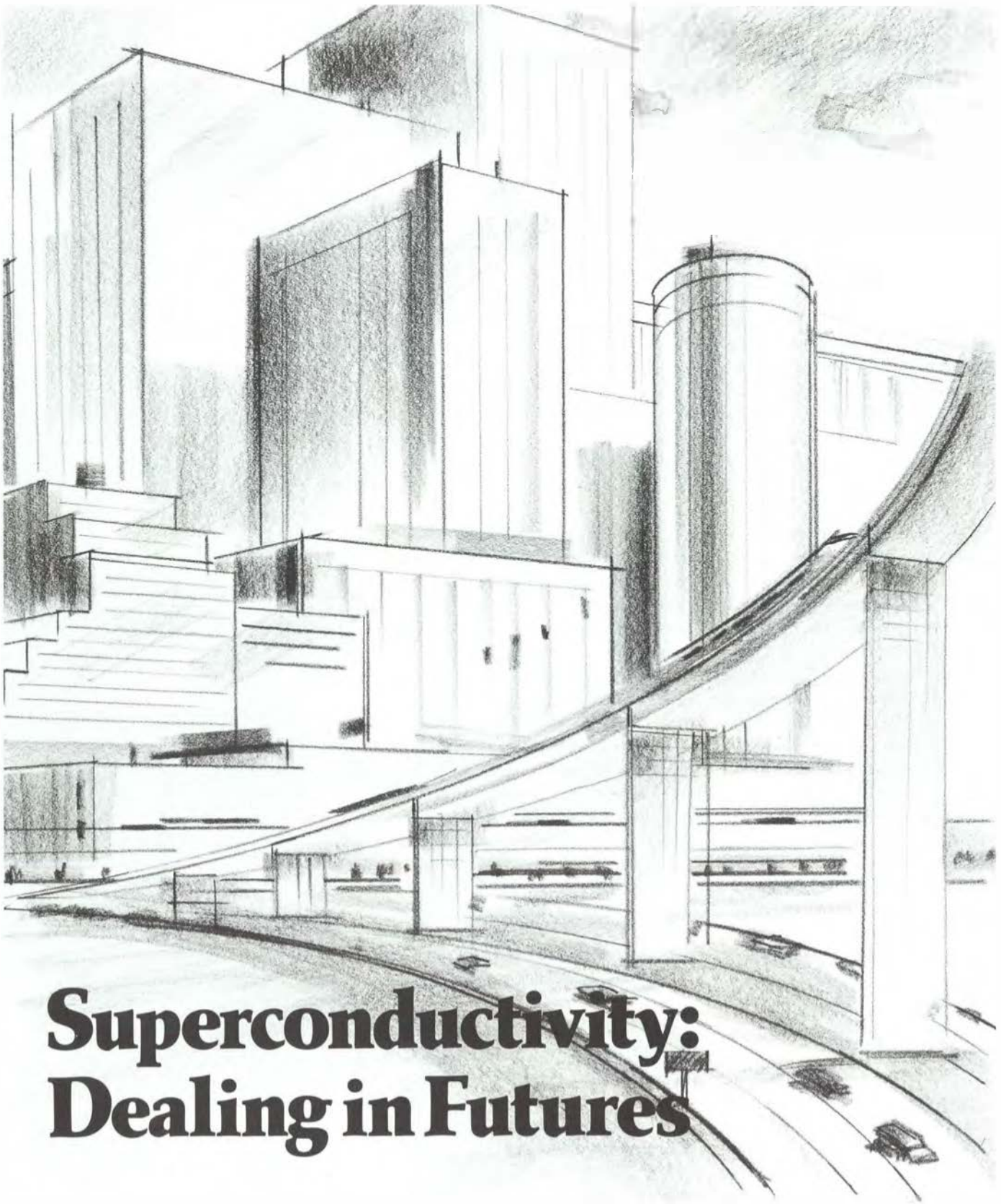
"AMEX (Average Magnetic Field Exposure) Dosimeter." EPRI Technical Brief TB.ENV.40.4.88.

"EMF: The Debate on Health Effects." *EPRI Journal*, Vol. 12, No. 7 (October/November 1987), pp. 4–15.

Electric and Magnetic Fields and Human Health. October 1987. EPRI videotape EA87-12.

"EMDEX System." EPRI Technical Brief TB.ENV.31.8.87.

This article was written by Taylor Moore. Technical background information was provided by Robert Black, Leeka Kheifets, Charles Rafferty, Leonard Sagan, and Stan Sussman, Environment Division, and Greg Rauch, Electrical Systems Division.



Superconductivity: Dealing in Futures

Although some of the excitement has subsided since the discovery of high-temperature superconductors (HTSCs) in 1986, R&D on these remarkable materials is still going strong at laboratories worldwide. A better understanding of the potential of HTSCs is now emerging, including cautiously optimistic hopes for such utility applications as superefficient generators and superconducting transmission cables. The news from the R&D labs, however, is that HTSCs in customer systems will probably precede applications in the utility grid. It is in the end use of electricity, in a wide variety of electrically powered machines, that HTSCs and other superconducting materials are likely to make their most immediate and greatest impact on utilities and the value of the electricity they provide.

The vision taking shape is one of lightweight, highly efficient superconducting motors driving pumps, fans, compressors, conveyors, and virtually every other kind of industrial machine. Superconducting machines that use magnetic forces for such tasks as separating ores and clays, pumping of corrosive and abrasive liquids, fabricating sheet metal, and improving the properties of ceramics, plastics, and metals may also come into wide use. In electronics, circuits fashioned with superconducting materials could boost the processing speed of computers, reduce resistance losses in motor controllers, and enhance the ability of magnetic resonance imaging scanners and other nondestructive examination devices to sense minute changes in magnetic fields. Even the processes of getting to work and traveling between major cities could be transformed by superconductor applications in magnetically levitated trains.

Although formidable technical barriers remain to be surmounted before any of these visions can be realized, the potential benefits to utilities and their customers are too great to ignore. To bring both the opportunities and the problems into focus, the U.S. Department of Energy and EPRI in

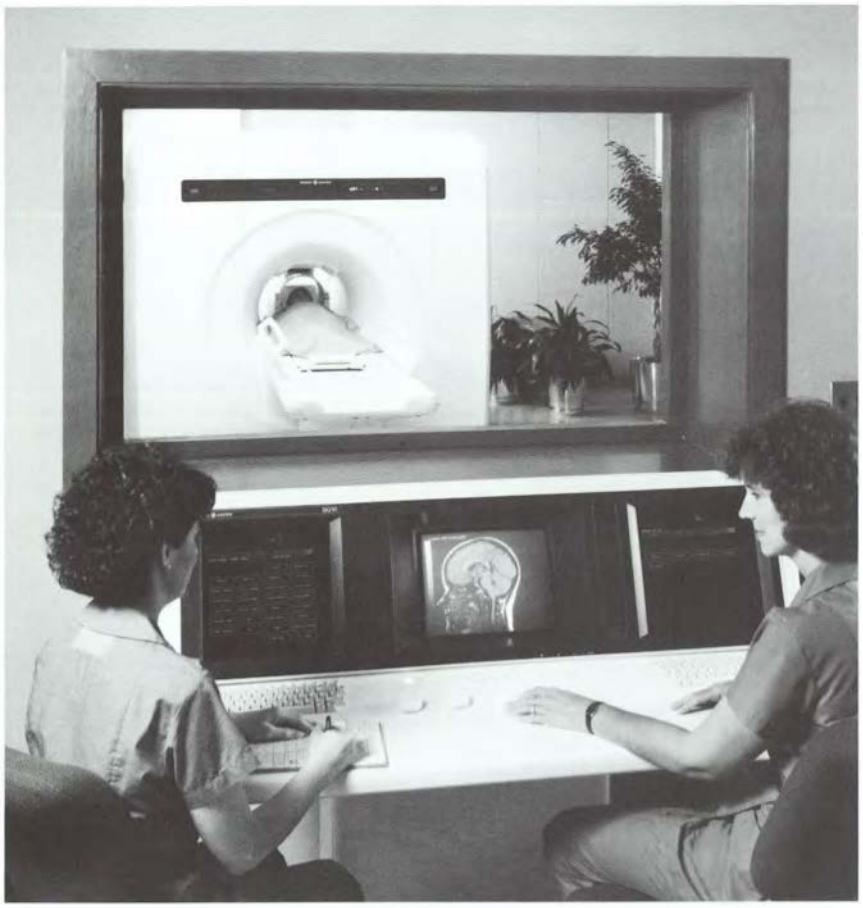
THE STORY IN BRIEF

Utility interest in the development of the new, high-temperature superconductors—HTSCs—goes beyond their possible application in the power grid. The introduction of HTSCs in customer applications is likely to have an even greater impact on utilities, increasing the value of electricity and expanding its use in virtually every area of life. According to a recently completed EPRI/DOE assessment, HTSCs could open a window of opportunity for many new uses of superconductivity—from powerful but compact electric motors to high-speed computers to magnetically levitated trains. Researchers are now working to narrow the gap between the potential of HTSCs and their engineering practicality and are looking for ways to shape the brittle ceramic materials into useful forms. Recognizing the enormous potential of these revolutionary materials for both customer and utility applications, EPRI continues to monitor and support the national effort to put HTSCs to work.

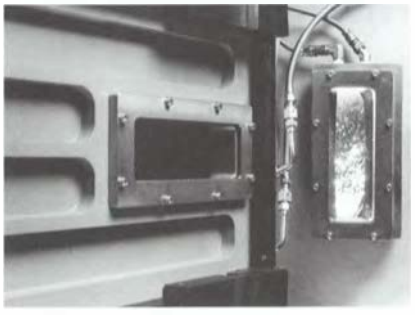
Superconductivity and Everyday Life

Specialized applications of low-temperature superconductors are already a reality in medicine, experimental physics, a prototype levitated train, and other kinds of machines. By reducing costs and improving performance, HTSCs could expand the use of these superconducting machines and lead to such entirely new applications as compact motors, electromagnetic pumps, and materials fabrication techniques.

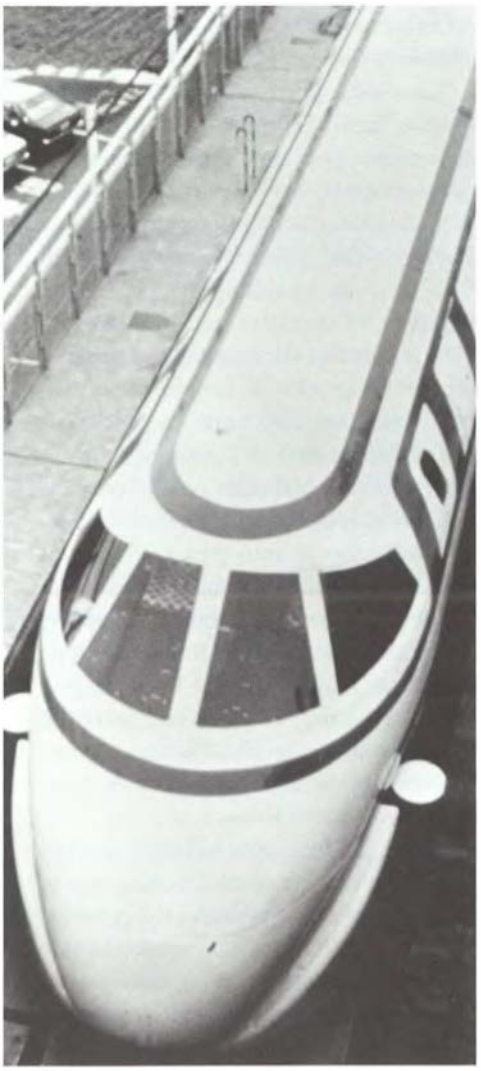
Clay purification system (Eriez Magnetics)



Magnetic resonance imaging (GE Medical Systems)



High-quality silicon manufacturing (UniSil)



Magnetically levitated train (Japan Railways Group)

Portable mineral separator (Intermagnetics)

Biomagnetometer (Biomagnetic Technologies)

early 1989 completed the first comprehensive assessment of superconductors and their potential for improving the energy productivity and capabilities of electrically powered equipment.

"We're looking squarely at the question, 'What good might superconductors be?' and learning that the answer could range across virtually every industry and area of life," says Thomas Schneider, senior scientific adviser in EPRI's Office of Exploratory Research. "By conceptualizing how we might bridge the gap between the scientific breakthroughs already made and the engineering practicality still in the future, we can better guide and set priorities for our R&D."

A question of feasibility

Superconductors have long showed potential for improving the efficiency and enhancing the capabilities of electrical and electronic systems. When cooled below a critically low transition temperature, superconductors lose all resistance to direct-current electricity; this property suggests that it might be possible to reduce or eliminate resistance in electrical systems, thus improving efficiency and generating stronger magnetic fields. In addition, superconductors show a unique tendency to exclude magnetic fields, known as the Meissner effect, which could conceivably be applied in new kinds of machines.

Some special applications of superconductors, such as magnetic resonance medical scanners and other scientific instruments, already exist. In addition, most of the large particle accelerators used in experimental physics employ superconducting magnets to control the direction of high-energy particles racing toward the experimental target. The metallic superconductors used in these systems, however, require extremely low temperatures to attain their superconducting properties. These transition temperatures of 23 K or lower can be achieved only by means of liquid helium refrigeration, which has proved too complex and costly for most ordinary uses of electricity.

Today, the discovery of HTSCs has revived visions of a role for superconductors in many different industries. Some of the new, ceramic HTSCs are superconductors at temperatures well above the boiling point of liquid nitrogen, a plentiful and thermodynamically efficient refrigerant that is literally cheaper than beer. The prospect of liquid-nitrogen-cooled systems has enlarged the window of opportunity for superconductivity applications. And if scientists should succeed in developing materials that become superconducting at room temperature, this vista will expand even further.

The obstacles to applications of HTSCs, however, seem built into the characteristics of the new materials themselves. Superconductors function as such only below certain critical values of temperature, magnetic field, and current density (the measure of the current a conductor carries per unit of cross-sectional area). HTSCs, to date, have demonstrated tolerances for relatively high temperatures and magnetic field strengths; this suggests they may become practical for many applications. But achievement of the most practically important characteristic—high critical current density—remains a vexing problem for researchers.

For applications developers, the challenge of achieving high current densities is complicated by other factors. First, the maximum current-carrying capacity of superconductors is reduced to a varying extent by magnetic fields, which would be present in all practical applications. Contact with water vapor and with conventional conductors and substrates—from copper to silicon—can result in chemical reactions with the HTSCs that can quench their superconductivity. In addition, HTSCs are superconducting only when carrying direct current; therefore, ac applications must include power conversion circuits or else sacrifice efficiency because of ac losses. The magnitude of HTSC ac losses is also not exactly known.

Facing these hurdles, scientists are attempting to produce HTSC materials that

can achieve and maintain high current densities in real-world conditions. This work has produced some success: current densities as high as several million amperes per square centimeter have been achieved with thin films of the materials. These films, however, have been produced only on rigid, impractical, and costly single-crystal substrates, such as strontium titanate, that do not rob the HTSCs of oxygen. Researchers are now exploring ways to insulate HTSCs from chemical reaction while depositing them on silicon wafers and other practical substrates that can be readily manufactured for use in electronic devices.

Other applications will require more flexible forms of superconducting material. Fashioning the brittle ceramic HTSCs into wires and other bulk conductors for use in electric motors and electromagnets is proving extremely difficult. One possibility now being studied is to make a bulk conductor out of many thin ceramic fibers that could be bound together into a sufficiently flexible superconducting wire. To date, the best wires produced this way have demonstrated current densities in the range of 1000 A/cm^2, far short of the 100,000 A/cm^2 that will probably be required for bulk applications. The Japanese, however, have achieved values as high as 17,000 A/cm^2 in a zero magnetic field by taking a different approach, in which powdered HTSC material is inserted into tubes of pure silver.

"Rather than developing the materials in forms used in conventional machines, it may prove more productive to develop applications around the forms of the materials that can possibly be made," says Dave Sharma, a subprogram manager in EPRI's Electrical Systems Division. "The interaction between applications development and basic research on theory and materials may produce entirely new equipment designs and uses for electricity."

Magnetic appeal

None of the possible applications for HTSCs would have more impact on energy productivity than use in electric motors, which account for about 64% of all electrical energy use in the United States. In conventional motors, the magnetic field in the air gap between the stator and rotor is generally limited to a range of 0.5–1.2 tesla by saturation of the field in the iron stator and by the risk of overheating from too large a current in the windings. Traditionally, designers increase the horsepower of motors by increasing the length and the radius of the rotor or by adding more turns in the winding.

A superconducting winding on the rotor, however, could make it possible to increase the magnetic field in the air gap to 5.0 tesla or more and thus boost power without necessarily adding to the motor's weight and volume. The strong magnetic field in the air gap would make it not only possible but necessary to operate the stationary ac winding without the traditional, flux-assisting role of the stator core iron. The stator core could be reduced in weight and volume, or even eliminated, further reducing core losses and making the motor even lighter and smaller. Overall, the reduction of losses from both the stator core and winding could make this superconducting motor extremely efficient.

In the recent EPRI/DOE assessment, researchers at Oak Ridge National Laboratory looked at several different superconducting motor concepts. One concept now in development at ORNL locates the dc superconducting field winding on the stationary portion of the motor. This unusual design, which uses a round superconducting stator bracketed by two rotating armatures, eliminates some of the complexity of supplying refrigerant to rotating components of the motor. Yet it remains to be seen if this novel approach can achieve the kind of energy efficiency and density that will make it practical. To explore the potential of the concept, ORNL researchers are now building a prototype that uses a low-temperature superconducting winding made of niobium-titanium. This research could help clear the path for an HTSC version of the motor as new materials become available.

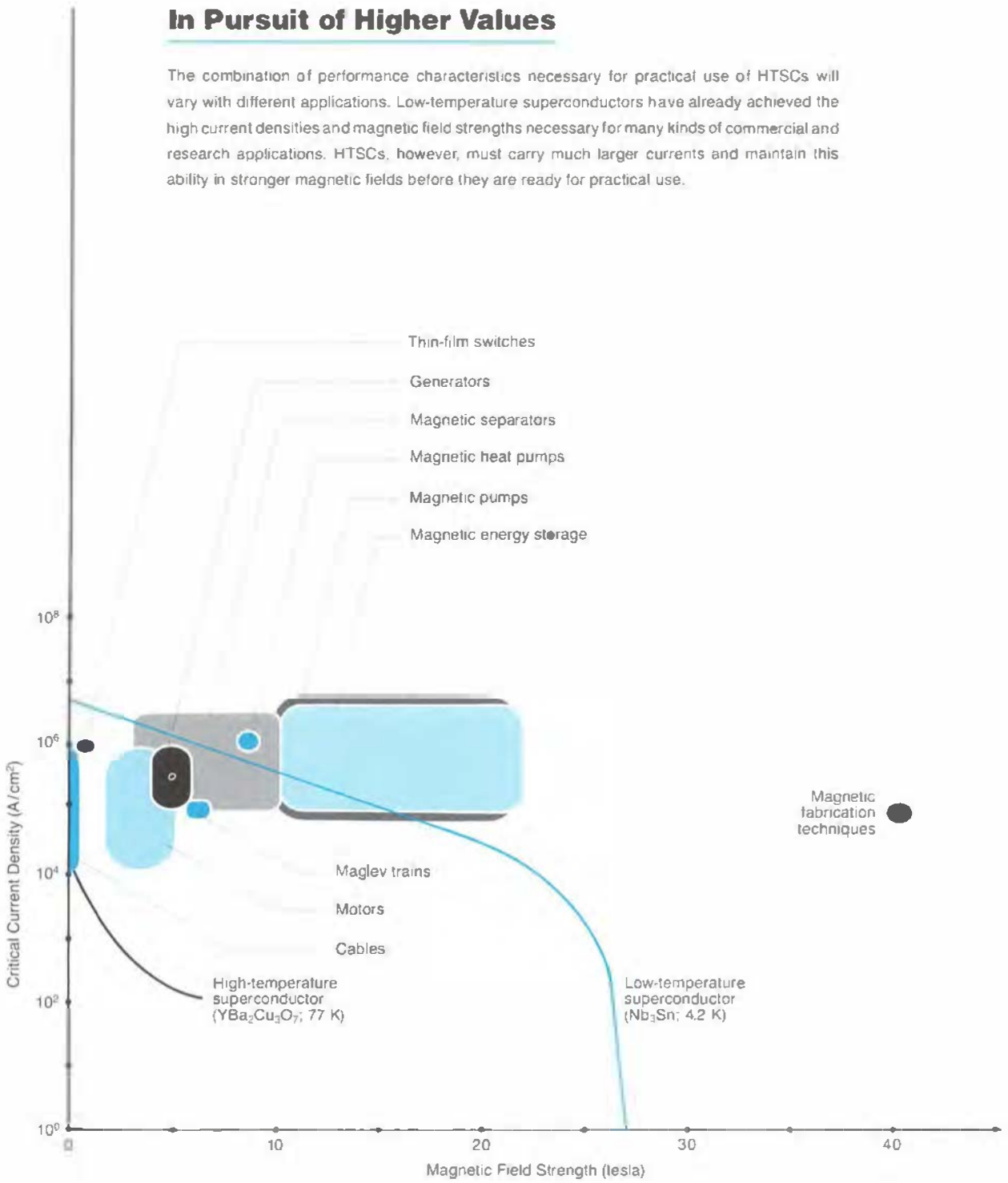
In a separate project, researchers under contract to EPRI at Reliance Electric Company are designing and building an HTSC electric motor in which the field winding, more traditionally, is located on the rotor. Like the ORNL design, this is an ac synchronous motor in which the superconducting component can be served with a direct current. Following selection of materials for an HTSC winding, researchers plan to build a 5-hp prototype by 1991. This work should help clarify such issues as the design of a practical refrigeration system, the shielding of the superconductor from magnetic interference, and the integration of power electronics.

"This prototype is not intended as a commercially viable system," says Jim Edmonds, a technical adviser in EPRI's Generation and Storage Division. "Our first prototype may even use a smaller magnetic field and be less efficient than a conventional motor, but what we learn in the process could be invaluable."

Beyond electric motors, many other kinds of system could exploit the ability of superconductors to produce strong magnetic fields. Magnetically levitated trains, or maglevs, are proving themselves in prototype demonstrations in West Germany and Japan. Levitated 10–15 cm above their guideways by the repulsion of electromagnets in both the vehicle and the track, maglevs can zoom straight into downtown urban areas at speeds of more than 300 mph. This could make them competitive in the United States with air travel for shorter routes, such as Boston to Washington, D.C., where traveling to and from the airport often consumes more time and worry than the flight itself. Analyses performed at Argonne National Laboratory show that the use of HTSCs in maglev electromagnets could bring down the costs of those components, reduce energy consumption by 10–15%, and make the entire levitation system easier and less expensive to maintain. Although these savings would subtract only a small fraction of the

In Pursuit of Higher Values

The combination of performance characteristics necessary for practical use of HTSCs will vary with different applications. Low-temperature superconductors have already achieved the high current densities and magnetic field strengths necessary for many kinds of commercial and research applications. HTSCs, however, must carry much larger currents and maintain this ability in stronger magnetic fields before they are ready for practical use.



cost of building and operating a maglev system, they could give a needed extra boost to a clean, energy-saving technology that increasingly seems to make sense.

A more down-to-earth group of technologies uses magnetic forces to separate particles with differing magnetic properties from process flows and from raw materials, such as the kaolin clay used in the paper industry. Although most magnetic separation systems use conventional electromagnets, a unique, liquid-helium-cooled system using a niobium-based superconducting magnet is now in service at the J. M. Huber Corporation clay processing plant in Georgia. Designed by Eriez Magnetics, the system has demonstrated superior capabilities and lower operating costs than the conventional alternatives. Again, the use of HTSCs and liquid nitrogen could make such systems even more attractive and broaden their use in many different industries.

The magnetic properties of superconductors may also prove useful in the production and fabrication of materials, many of which can be engineered into useful shapes and, more fundamentally, restructured at the molecular level when subjected to magnetic fields. Scientists in Japan and the Soviet Union have demonstrated the use of magnetic forces to align crystals within such materials as silicon and ceramics into the uniform structures needed for superior performance. Also, it is known that polymers formed in high-magnitude fields exhibit greatly increased strength due to the better alignment of individual molecules with the fiber axis, but no industrial processes have yet been developed to exploit this effect. The availability of powerful and economical magnets using practical HTSC materials might change this.

Superconductors also show potential for use in the large-scale fabrication of metals and other materials, where researchers are exploring the use of magnetic forces to mold solid materials into sheets or rods, or hold liquid materials—such as ultrapure silicon—in a levitated

Improving Crystal Structure

Scientists have identified the random crystal structure of HTSCs as a factor that impedes the movement of electrons through the material and limits current density. Using magnetic forces to realign the HTSC crystals, EPRI-sponsored researchers at the University of Wisconsin at Madison are studying the relationship between crystal structure and achievable current density.

Random crystal structure

Magnetically aligned crystals

state so as to avoid contact with molds or dies. Just as advances in digital electronics created the design systems needed for further progress in that field, application of new materials to fabrication and processing tasks may help move the entire field of materials science forward.

Enhanced electronics

Exquisitely sensitive electronic instruments such as magnetic resonance imaging scanners and superconducting quantum interference devices (SQUIDs) represent the largest commercial application of superconductors today and could be made smaller, less costly, and easier to use through application of the new HTSCs. SQUIDs, which employ electronic sensors to monitor tiny disturbances in magnetic fields generated by superconducting magnets, are currently used in geological research and in medical instruments—for detecting changes in soft tissue inside the brain caused by head injuries, epilepsy, and other abnormalities.

The use of HTSCs could reduce the bulky insulation needed to house liquid helium for these instruments, improving their effectiveness by making it possible to position them closer to the body. HTSCs could also reduce the size and possibly lower the capital costs of superconducting instruments for detecting microwaves and heat, with one possible application being detection of submarines lurking far below the ocean surface.

Much of the extensive research being financed by the electronics, computer, and communications industries in the United States, Japan, and Europe today is motivated by the possibility of incorporating superconductors into many kinds of electronic circuits and switches. Research on ultrafast superconducting computers is still in an early stage, but these applications may be among the earliest ones because they will require only superconducting films. A more relevant development from the standpoint of electric utilities may be the use of superconductors in motor controllers and other power

Challenge for Long-Range Research

A veritable obstacle course of technical hurdles faces researchers attempting to develop applications for HTSCs. The most thorough assessments of these challenges are cautiously optimistic, emphasizing the need for a commitment to long-range research.

Two reports on HTSCs, one recently published by Japan's Nikkei Research Institute of Industry and Markets and the other issued by the Congressional Research Service in the United States, predict that the first HTSC applications are at least 5–10 years away. The reports agree that these first applications are likely to use HTSC thin films in the circuits of medical sensors, microwave detectors, switches, and other electronic devices. The development of more flexible and versatile substrates for the thin films is a major goal of current research, along with the invention of economical methods for manufacturing the films on a large scale.

Applications requiring bulk materials, such as electric motors, magnetic separators, and other heavy industrial equipment, are at least 10 years in the future. Here researchers must contend with the poor mechanical properties of ceramic HTSCs while also looking for forms—such as fibers, wires, or tapes—that can maintain their superconducting properties while carrying larger currents.

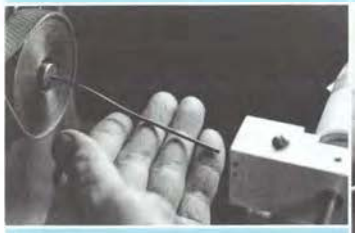
The effort to surmount these and many other obstacles is now in progress around the world, involving thousands of researchers in both private and public laboratories. The United States and Japan have taken lead roles in this work, with American researchers at the forefront of materials and theoretical research and the Japanese somewhat ahead in the development of commercial applications. Looking to narrow this gap, private organizations that include such technology giants as IBM, AT&T, Dupont, and Hewlett-Packard have stepped up collaborative HTSC projects with researchers at universities and national labs. To ensure that utility interests are represented in the development of applications for both power companies and their customers, EPRI is continuing to monitor and participate in these efforts of national importance. □

Producing Practical Forms

Practical use of HTSCs will require material forms with the right balance of performance characteristics and mechanical properties (e.g., flexibility and durability). Researchers around the world are experimenting with several material forms that could prove useful, including HTSC wires, coils, tapes, and cables.

Making Coil at Argonne At Argonne National Laboratory, a national center for HTSC applications work, researchers have succeeded in shaping the brittle material into a flexible coil for use in such applications as electromagnets, electric motors, and generators. A paste of HTSC material and a binding agent is extruded into a string, which is rolled into a coil and baked into a flexible, superconducting form. The finished product is then bathed in liquid nitrogen to test its current-carrying capability.

Extruding the paste



Rolling the coil

Finished product

Testing for current density

Making Tape at Madison EPRI-sponsored researchers at the University of Wisconsin at Madison make an HTSC tape of their investigations of current density and other performance characteristics. HTSC material in powdered form is inserted into a silver tube, which is stretched into wire and then rolled into a flat metallic tape with a superconducting center.

Filling silver tube with HTSC powder

Drawing wire from filled tube

Rolling wire into flat tape

Powdered HTSC with silver tube and finished tape

electronics components used to control and manipulate electricity at relatively high currents and voltages. Motor controllers consume about 1% of the energy used by electric motors, an energy loss that might be entirely eliminated through the application of thin-film superconductors in power switches.

The use of thin-film superconductors in power electronics devices could also improve the efficiency of superconducting motors, all of which will require electronic controllers. If scientists should eventually develop room-temperature superconductors, their application in the electronic ballasts used to control fluorescent lights could produce large energy savings.

New life for old technologies

An element of the excitement caused by the new HTSCs is the possibility that they may enable the application of certain existing technologies on a much larger scale. The use of superconducting magnetic heat pumps in commercial and industrial refrigeration, for example, although it seems farfetched today, may eventually prove practical with the development of HTSCs. Small-scale versions of these systems, using conventional electromagnets, are used in scientific laboratories to achieve extremely low temperatures. They work on the basis of a property of gadolinium and other rare earth materials to absorb heat when subjected to magnetic fields and then release heat when the field is taken away. Substances exhibiting this magnetocaloric effect can thus function as refrigerants do in conventional cooling cycles or heat pumps, absorbing and releasing heat.

With superconductors delivering the magnetic fields needed to induce these temperature changes, the resulting gains in energy efficiency compared with conventional systems might more than offset the high costs of rare earths. The EPRI/DOE assessment emphasizes that discovery of alternative, less costly magnetocaloric materials could help developers make this technology practical on a much larger scale.

Another exotic technology that could become more commonplace with the application of superconductors is the electromagnetic pumping of corrosive and abrasive fluids, which often cause maintenance problems in conventional pumps and prove difficult to transport. Electromagnetic pumps have no seals or moving parts that come in contact with the working fluid, making them attractive candidates for a range of troublesome pumping tasks. They use the reaction of a magnetic field and an electric current introduced into the fluid being pumped; so far they have been limited to the pumping of extremely conductive fluids such as the liquid metals used in breeder reactors.

The more efficient and economical generation of magnetic fields through the use of superconductors might make electromagnetic systems more practical for pumping less conductive fluids such as coal slurries, many kinds of corrosive or abrasive chemicals, and radioactive wastes. A related scheme, using the interaction between a magnetic field and a current applied to a channel of seawater pumped through an oceangoing vessel, has been suggested as a possible breakthrough propulsion system for large ships.

From the possible to the practical

While researchers look at the problems of feasibility and scale involved in broadening the applications of electromagnetic pumping and other technologies, new ideas for uses of superconductors and electricity are emerging all the time. These visions range from propulsion systems for a new generation of electrically powered vans and cars to improved photovoltaic cells for solar power generation.

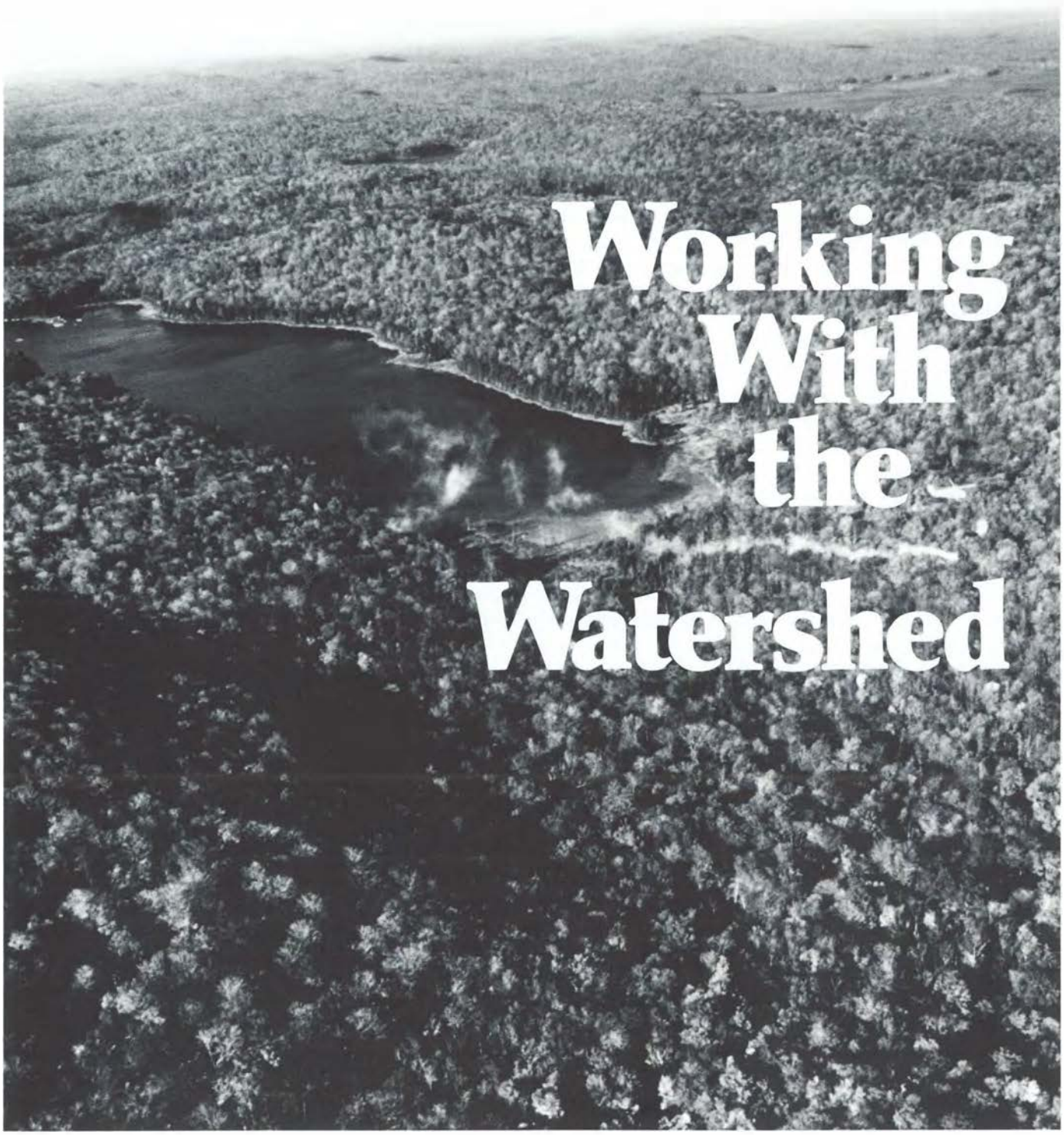
As researchers work to develop new materials and fabricate more useful forms of the ones already at hand, they will continue to narrow the gap between the promise of superconductors and their seemingly boundless possibility for application. As materials performance barriers are surmounted, issues of cost and scale are likely to come more clearly into relief. The expanded use of low-temperature superconductors in applications such as motors and generators, materials separation, maglev transportation, and medical diagnostics may help clear up some of the economic questions that will bear on the eventual use of HTSCs.

"It's clear that many industries besides the electric utilities have an interest in the development and application of superconductors," says Schneider. "These materials have enormous potential to increase the value of electricity to our customers in virtually every area of life, and to increase the benefits of electricity to society." ■

Further reading

Energy Applications of High-Temperature Superconductivity, Vols. 1 and 2. Summary report for RP8009-2, prepared by Steinar J. Dale, Stanley M. Wolf, and Thomas R. Schneider, January 1990. EPRI ER-6582.

This article was written by Jon Cohen, science writer. Technical background information was provided by Thomas Schneider, Office of Exploratory Research; D. K. Sharma, Electrical Systems Division; and Jim Edmonds and J.C. White, Generation and Storage Division.



Working With the Watershed

Ackerman Lake in central Michigan is a trout angler's Shangri-la. Its slightly alkaline water supports a vigorous aquatic community—trout grow large and strong feeding on an abundant variety of insect species and freshwater shrimp, attracting fishermen from around the world, who provide an important source of revenue to the local economy. Ackerman Lake's bounty is made possible in part by the calcium-rich soils and limestone formations that surround its shore. Rainwater and snowmelt flowing through the watershed deliver a steady supply of natural acid-neutralizing material to the lake, preserving the favorable chemical environment in which Ackerman Lake's residents thrive.

Thousands of other lakes, however, lack such a natural capacity to buffer acid. Woods Lake in New York's Adirondack Mountains, for example, is surrounded by weathered rock and shallow soils that are deficient in acid-neutralizing compounds. It's also downwind of major industrial and metropolitan centers whose factories, power plants, and automobiles emit acid-precursor chemicals. Natural processes, such as the decomposition of organic matter, also serve as sources of acids in the basin. Acids carried in the water flowing through the soil of the watershed are only partially neutralized before entering the lake itself.

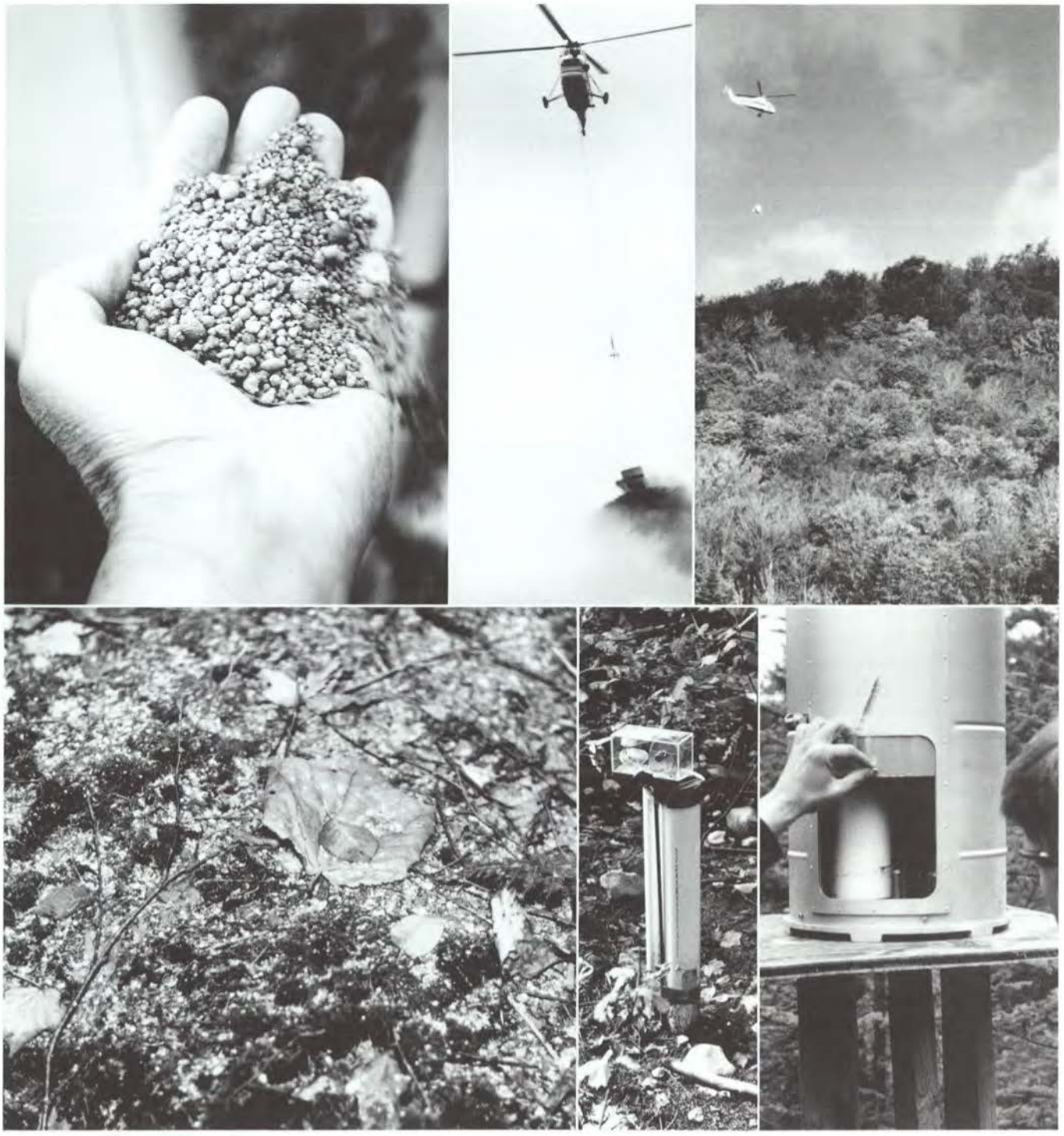
Woods Lake is one of many acid waters that are unable to support healthy populations of game fish. It has also been a subject of extensive environmental study since the mid-1970s, when EPRI researchers began collecting data to learn why Woods was more acidic than two neighboring Adirondack lakes sharing similar characteristics and receiving similar inputs of acid rain. Some of the knowledge acquired during the course of that research is now being applied in a new experiment—watershed liming—that seeks to give Woods Lake a line of defense against acid similar to the one that naturally protects Ackerman Lake.

THE STORY IN BRIEF

Adding limestone to acidified lakes has proved an effective and environmentally sound method of restoring populations of game fish and other aquatic life. Building on successful experience with lake liming, researchers are now going a step further by liming a watershed—the land surrounding a lake—rather than the lake itself. Applied by helicopter, the limestone dissolves and saturates the ground with calcium ions, which neutralize acidic runoff before it reaches the lake. Researchers are interested in whether deep soil layers are neutralized and how that affects the duration of treatment. Over the next two years, researchers will measure changes in soil and in the acidity of the lake and its tributaries, as well as monitor effects on aquatic life. A parallel experiment in West Germany will lime a forested watershed to study effects on the terrestrial ecosystem. An objective of both projects is to evaluate a computer model that simulates lake-watershed processes.

Liming the Watershed

For the October liming operation, pelletized limestone was trucked to a staging area near Woods Lake and was applied by a helicopter equipped with a commercial fertilizer spreader. Pellets penetrate the forest canopy more effectively than powdered limestone, permitting uniform coverage of the areas selected for treatment. Researchers will monitor the treatment's effects on the lake-watershed ecosystem for the next two years.



Restoring an ecosystem

Last October, limestone pellets were applied by helicopter to the forested slopes above the two tributary streams feeding Woods Lake. Autumn showers quickly dissolved the limestone, allowing it to soak in and saturate the top 15 cm of soil. The idea is that calcium ions liberated from the limestone will increase the soil's buffering capacity, allowing it to neutralize acidic inputs to the tributaries and the lake. Over the next two years researchers will measure changes in the acidity of the lake and streams, as well as monitor the treatment's effects on the aquatic community and the terrestrial ecosystem.

EPRI is managing the project, with technical and financial support provided by Living Lakes, a private not-for-profit organization established to demonstrate that liming is a feasible strategy for restoring acidified waters. Additional funding is being provided by the Empire State Electric Energy Research Corporation, the U.S. Geological Survey, and the U.S. Fish and Wildlife Service Cornell University, Syracuse University, Clarkson University, Smith College, and the State University of New York at Syracuse will assist in the research.

"The Woods Lake watershed liming experiment will provide a unique opportunity to understand the underlying processes affecting acidification and neutralization," says Donald Porcella, project manager in the Ecological Studies Program. "The results will help explain the functioning of watersheds and their ecological communities and will provide additional information on how to restore and maintain fisheries."

The experiment will also provide researchers with hands-on experience in the practical aspects of conducting such an operation. In the future this knowledge may be transferred to private organizations or government agencies who may be liming watersheds on a regional scale. In designing the Woods Lake watershed liming experiment, researchers systematically addressed a variety of ecological and logistical concerns, including the quantity and the nature of the limestone to be applied, the amount of watershed area to be treated, and the seasonal timing of the application.

Two areas above Woods Lake, representing roughly 40% of the total watershed, were chosen for treatment because they have thick soils and encompass the primary tributary streams. Coordinates were set up in these areas to mark application paths for the helicopter pilot to follow. The helicopter distribution system used in the experiment consisted of a commercial fertilizer spreader that holds 4000 pounds of limestone, which was suspended by a cable attached to the underside of the helicopter. This arrangement sped loading times by allowing the helicopter to hover over a staging area while technicians on the ground refilled the spreader. After flying his craft to the treatment area, the helicopter pilot used a radar navigation system to apply the limestone precisely in successive paths to achieve uniform coverage of the selected areas with precalculated dosages of 4–5 tons per acre. The round-trip time for each flight was about six or seven minutes.

The limestone itself was carefully selected. "We require a very high calcium carbonate content—93%," says Porcella. "It's pelletized so it will penetrate the forest canopy and give us a more uniform treatment than is possible with a dry powder." Conducting the operation in the fall had several advantages, according to Porcella. "It's the time of year when the trees are losing their leaves, so the falling pellets won't damage the forest canopy. And of course there's a lot of rainfall during that period, so the limestone rapidly dissolves and saturates the upper layers of the soil."

Building on experience

Adding limestone to improve the productivity of soil and water has been practiced since the time of the Romans. Farmers routinely add agricultural lime to their fields to neutralize acidity, and over the past 30 years several government and private organizations in the United States and Europe have added limestone directly to lakes to counter acidification. According to Robert Brocksen, executive director of Living Lakes, liming has matured beyond the research stage and into a practical tool for restoring acid lakes and streams.

Living Lakes, which receives about $3 million annually from utilities and coal companies, has taken the lead in the liming effort in the United States, developing methodologies for calculating optimal lime dosages for specific waters and using an array of apparatus to apply the limestone. Helicopters, fixed-wing aircraft, barges, and pumps have been used to lime 40 lakes and 13 streams in different areas of the United States.

The U.S. liming effort pales in comparison with that of Sweden, which has limed some 4000 lakes to date and has about 6000 more ticketed for treatment. "Liming is a fisheries management tool," says Brocksen. "It's a way of altering water quality to benefit aquatic organisms."

Adding limestone to an acidified body of water produces rapid and dramatic results. The alkaline limestone quickly neutralizes the water's acidity, allowing fish and other members of the aquatic community to reestablish themselves and displace acid-tolerant organisms that may have taken hold while the lake acidified. Porcella and Brocksen emphasize that no deleterious effects have been observed as a result of liming.

Adding limestone directly to a lake has its limitations, however. For many lakes, such as Woods, the benefits of direct liming are short-lived because their water is constantly being replaced. As water flows from the lake's outlet stream, the limestone is flushed away as well, so the treatment has to be repeated when the limestone is exhausted. Moreover, liming the body of a lake does not neutralize acidic water flowing in from the watershed. The tributaries and groundwater flows feed-

ing the lake continue to deliver their burden of acid. The problem is especially acute during the spring and fall, when snow runoff and storms introduce surges of acidified water into feeder streams and shallow areas near shore, both of which provide important habitat for spawning fish and for fish nurseries.

Long-term benefits

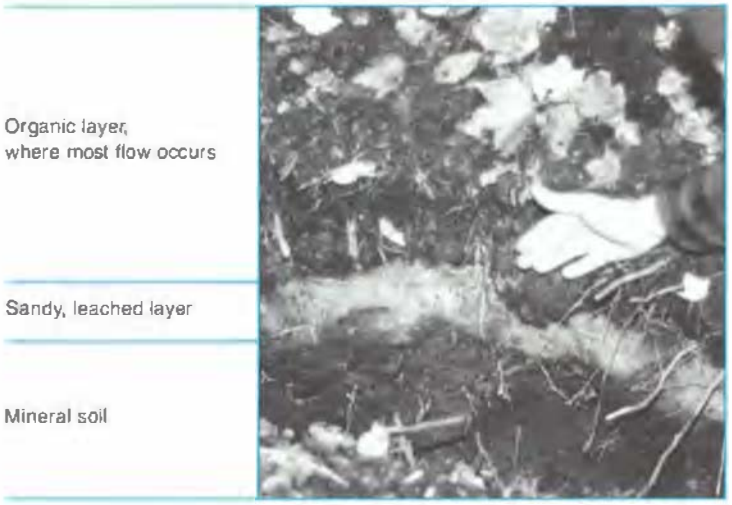
By liming the Woods Lake watershed, rather than the lake itself, researchers hope to overcome these limitations. "We expect that the dissolved limestone will be effective in neutralizing acid for the next 5–10 years," says Porcella. "We will be monitoring it to see whether it actually does last that long. We also want to see whether the treatment will increase the habitat for fish by making the tributary streams available to them, and whether it will take care of episodic acidification—the pulses of acids that enter the shallow-water areas of the lake after storms or snowmelt."

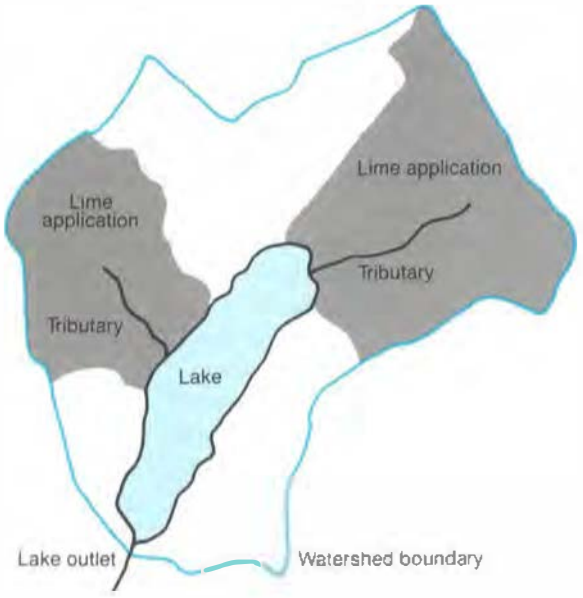
Watershed liming is thus an ecosystem approach to restoration that is built on the results of more than a decade of EPRI research on the environmental effects of acid rain. Much of this research has focused on the Adirondack region, where acid rain has been blamed for the decline of fisheries in numerous high-elevation lakes. To examine the processes involved in lake acidification, EPRI assembled a team of researchers representing several scientific disciplines to study three lakes in Adirondack Park—Woods, Panther, and Sagamore—from 1976 to 1984. This ambitious project, the Integrated Lake-Watershed Acidification Study (ILWAS), produced a wealth of information on the processes that determine why some lakes acidify while others do not. The researchers quickly learned that lake acidification was far more complex than previously thought. For example, each of the study lakes, located within 30 km of each other and receiving nearly identical inputs of acid, registered a different level of acidity. Woods Lake was found to be acidic, with an average pH of 4.7, while Panther Lake was neutral, with an average pH of 7. The pH of the third lake, Sagamore, fluctuated between that of Woods and that of Panther. Why the difference?

Robert Goldstein, who managed the ILWAS project for the Ecological Studies Program, explains. "Prior to ILWAS there existed a widespread misconception concerning surface water acidification," he says. "Many people believed that a lake was like water in a beaker, and acid rain was like adding acid to that beaker—that a single factor determined the acid-base status of lakes. What ILWAS demonstrated was that the acid-base status of water in a lake or stream is not simply a function of what's falling directly into it, but rather a function of multiple environmental factors. As precipitation moves from the atmosphere to the lake, it can follow different pathways. It can fall directly into the lake, or it may first be intercepted by the terrestrial ecosystem. There, it can flow on the surface of the soil, or it can flow through the upper, or-

A Line of Defense Against Acid

Some lakes are naturally protected from acidification because water draining into them flows through deep soils rich in acid-neutralizing materials. The shallow soil around Woods Lake has little acid-neutralizing capability—a condition that researchers aim to remedy by liming the watershed. As the limestone dissolves, it saturates the soil with calcium ions; these ions neutralize acidic runoff before it enters tributary streams and the lake itself. Researchers will measure the effective duration of watershed liming compared with that of lake liming and will determine whether tributaries become available to spawning fish.





ganic layers of the soil, which are acidic, or it can flow into the lake through the deeper, inorganic layers, which are neutral. Depending on the pathway that the water follows, it will come into contact with different components of the ecosystem. In each of these components there are processes that can change the water's chemical composition."

The average depth of the soil in the Panther Lake watershed is about 20 meters, while the average soil depth of Woods is about 2 meters. In addition, the Panther soils are more permeable than those at Woods. Consequently, acidic water moving through the Panther Lake watershed penetrates deeper and remains in contact with the soil particles for a longer period of time, allowing for more neutralization to take place before the water enters the lake. In contrast, most of the water flowing through the less permeable soil around Woods remains in the acidic upper layers, so only further acidification occurs.

Goldstein's ILWAS team developed a general theory for understanding how such watershed processes interact to influence lake chemistry. The theory has been incorporated into a computer simulation model that predicts a lake's vulnerability to acidification. The ILWAS model is now used by utilities, by the U.S. Environmental Protection Agency, and by other organizations in the United States and Europe as a tool to predict how changes in atmospheric acid deposition will change the acidity of surface waters. The National Acid Precipitation Assessment Program (NAPAP) is using the model's predictions in forming recommendations on emissions control strategies that will be contained in its final assessment report, scheduled for release next fall.

ILWAS model simulations were used in the design of the Woods Lake experiment. The actual liming of the watershed will in turn provide an opportunity to put the ILWAS model through a rigorous test of its predictive powers, according to Goldstein. The data obtained by field measurements will reveal how the ecosystem is responding to the limestone treatment, and will be compared with the model's predictions to determine how accurately the model mirrors the changes that are taking place in the real world.

"In all the cases where we've used the model to date, the lake-watershed systems have been more or less in equilibrium," Goldstein says; "they're not changing with time. Yet the best test of the model is when systems change dramatically. This experiment will allow us to really test the entire workings of the model: how it predicts the movement of water through the watershed, and how it simulates all the biogeochemical processes that influence the composition of the water as it moves through the entire ecosystem."

The ILWAS model will also be put to the test in a related experiment being conducted in the Black Forest of West Germany. For more than a decade the forest has shown symptoms of decline in the form of needle losses and discoloration, which may be the result of soil acidification and nutrient deficiencies. This spring the Schluchsee Experimental Watershed in the southern portion of the Black Forest will be limed by the Institute of Science and Forest Nutrition of the Albert-Ludwig University in Freiburg. Conducted as a cooperative effort, the Woods Lake and Schluchsee watershed experiments share similar objectives, approaches, and measurement techniques but differ in the purpose of treatment. The German study's main objective is to evaluate the treatment's ability to revitalize and maintain the ecological functions of a managed forest. The American study, in contrast, is directed primarily to the effects on the aquatic ecosystem. "These similarities and differences will make the results more interesting and more broadly applicable," Porcella notes. The ILWAS model will be used to integrate the results from the Adirondack and Black Forest sites because geographic and climatic differences in the two regions make comparisons difficult. The opportunity to test the ILWAS model may prove to be one of the most valuable aspects of the coordinated effort, according to Porcella. "The experiments in the two different watersheds will provide the most rigorous test of the ILWAS model to date," he says.

A practical option

Research by EPRI and Living Lakes, as well as that conducted in Europe, has shown liming to be a safe and cost-effective mitigation technique. The practice has been criticized, however, as a Band-Aid solution that does not treat the problem of acid rain at its source. Such a view reflects a narrow perspective, according to Brocksen, who maintains that liming is a useful tool for managing water quality that makes scientific and economic sense regardless of what regulatory actions are taken to control the emissions of acid precursors.

"There are multiple sources of acidity," he says. "But even if we presume that the bulk of that acidity comes from stack emissions and that further emissions reductions will be mandated, the best scientific estimates indicate that it may take 20–50 years or more for some of the affected lakes to recover on their own." Thus even with emissions control of acid precursors, liming would still be a practical way to hasten the recovery process.

Further reading

"Lake Acidification Mitigation Project." *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 46, No. 2 (February 1989), pp. 246–358.

Restoration of Aquatic and Terrestrial Systems. R. W. Brocksen and J. Wisniewski. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1989.

"Restoring Life to Acidified Lakes." *EPRI Journal*, Vol. 11, No. 3 (April/May 1986), pp. 14–21.

"Lake Sensitivity to Acid Rain." *EPRI Journal*, Vol. 10, No. 5 (June 1985), pp. 16–21.

The Integrated Lake-Watershed Acidification Study, Vol. 4: Summary of Major Results. Final report for RP1109-5, prepared by Tetra Tech, Inc., November 1984. EPRI EA-3221.

This article was written by David Boutcher. Background information was provided by Donald Porcella and Robert Goldstein, Ecological Studies Program, and Robert Brocksen, Living Lakes, Inc.

TECH TRANSFER NEWS

$6 Billion Benefit From EPRI Research

Some of the largest benefits of collective R&D accrue in environmental research, where results can help establish a scientific basis for recommendations on industrywide regulatory policy. A recently completed EPA analysis of EPRI's findings on fossil fuel combustion wastes illustrates how the aggregate savings of electric utilities can total billions of dollars.

EPA and electric utilities were given time to develop a better understanding of the character and environmental consequences of scrubber sludge, coal combustion ash, and related wastes when Congress (in 1980) adopted amendments to the Resource Conservation and Recovery Act (RCRA). Because of the cost to change how these high-volume wastes are handled, they were temporarily exempted from hazardous-waste classification and regulation. But the RCRA amendments also called for EPA to study the matter and "submit a report on the adverse effects on human health and the environment, if any," from the disposal and use of fly ash, bottom ash, FGD scrubber sludge, and other by-products of fossil fuel power generation.

In response to the amendments, the Edison Electric Institute and the Utility Solid Waste Activities Group (USWAG), an ad hoc committee of utility representatives, began supplying information to EPA. And EPRI's Solid Waste Environmental Studies project, established at that time, provided a foundation of independent research on which both USWAG and EPA came to rely heavily.

EPA's report from its work, *Wastes From the Combustion of Coal by Electric Utility Power Plants*, appeared in 1988. It cited 21 EPRI reports dealing with such matters as the chemical and physical characteristics of the wastes, their leaching and transport in the environment, groundwater analyses at disposal sites, and extraction methods for waste treatment and reuse. The EPA report came up with three findings:

- That high-volume wastes from coal combustion (mainly ash, sludge, and slag) should be classified as nonhazardous for regulation under federal and state programs
- That reuse of those wastes in an environmentally sound manner should be encouraged
- That a number of low-volume materials, such as boiler cleaning waste and demineralizer regenerant, may merit classification as hazardous waste

Since the EPA report came out, EPRI-sponsored researchers have continued to improve and validate models and develop new data for predicting the release of chemicals from utility waste and for tracking their transport, transformation, and ultimate fate in the environment. Now, newly proposed RCRA amendments that could change EPA regulation of combustion wastes in the 1990s make this ongoing work all the more timely.

But during the interval between the 1980 amendments and the time any new amendments are likely to take effect, EPA estimates, the utility industry will save roughly $3.7 billion annually—the avoided cost, nationwide, for design and implementation of the new facilities and procedures that would be needed if the high-volume wastes from coal-fired power plants were classified as hazardous. The total benefit could amount to more than $18 billion over the next five years—and USWAG attributes nearly $6 billion of that saving to EPRI. The costs of cleaning up old plant sites would add up to that much, as would the loss of revenue that would result from regulations restricting the sale and reuse of fly ash and other wastes for construction and other uses. ■ *EPRI Contact: Ishwar Murarka, (415) 855-2150*

Production-Line R&D Cuts Transformer Core Cost

Manufacturability is the bottom line in technology development; it marks the last opportunity to control product cost. In the case of new distribution transformers with low-loss amorphous metal cores, utility R&D involvement in manufacturing techniques is expected to make the difference between unrealized market potential and broad commercial success.

Several years of R&D and field testing since the 1970s have yielded complete technical success for the advanced transformers—but clear economic benefit only for utilities whose plant costs, interest rates, demand charges, and replacement power costs establish a high value ($5 a watt or more) for any power that can be saved by transformer efficiency. In a few cases, regulatory pressure to reduce system electrical losses has added to the market.

The early amorphous transformers were expensive. The cost of the thin, brittle amorphous metal strip itself and the cost of the labor-intensive core construction limited the initial market, according to EPRI project manager Harry Ng. Since 1987, therefore—about when the first commercial units were sold—EPRI has also sponsored development of cost-effective manufacturing techniques.

The result is a computer-driven production line that started up in December 1989 at a GE transformer plant in Hickory, North Carolina. Automated processes cut the ribbons of amorphous metal and assemble them into complete cores. Because the core laminations are only about 0.001 inch thick (about one-tenth the thickness of conventional core steel), extraordinary precision is required in cutting the sheets of metal and assembling them into cores.

Economies at this key manufacturing stage should help bring down the initial cost of the transformers so that their competitive advantages of energy savings and lower operating costs show up better. "We're nearing the point at which amorphous-core transformers will be competitive for at least half the U.S. utility market," says Harry Ng. "There are about 25,000 amorphous units now in service, but the figure ought to grow rapidly in what is now a much more competitive transformer market."

Compared with conventional units, amorphous-core transformers reduce no-load electrical losses by 60–70%. EPRI estimates that nationwide use would save billions of kilowatthours, with an annual value of $300–700 million. For specific product information, contact Larry Lowdermilk at General Electric in Hickory, North Carolina, (704) 462-3113. ■ *EPRI Contact: Harry Ng, (415) 855-2973*

Validation Speeds Use of IGSCC Remedy

EPRI's authentication of new repair and maintenance techniques for utility equipment helps speed the transfer of these technologies from the laboratory to the power plant. Recently, for example, Commonwealth Edison turned to EPRI's Repair Applications Center (a specialized activity of the NDE Center in Charlotte, North Carolina) to confirm the effectiveness of a technique—and equipment—for mechanically squeezing a pipe to prevent intergranular stress corrosion cracking (IGSCC) in BWR systems. EPRI's evaluation contributed to NRC approval of the process, and its subsequent use at six Commonwealth BWRs produced a benefit assessed by the utility at more than $400 million.

Developed by SMC O'Donnell, Inc., the mechanical stress improvement process (MSIP) features a clamp that introduces a beneficial compressive stress at welds that are susceptible to IGSCC. In combination with regular inspections, MSIP can help utilities avoid the extra in-service inspections and costly pipe replacements that have been necessary at many BWRs.

The new technique appeared cost-effective early on, but Commonwealth needed an objective evaluation and conclusive evidence of MSIP's reliability in order to gain acceptance from the NRC. Here is where the Repair Applications Center was helpful, providing both expert staff and a large-diameter pipe-to-fitting mockup for testing the process.

Before-and-after strain measurements documented that MSIP changed the residual stresses near the welds from tensile to compressive. The test results were submitted to the NRC, which approved MSIP as an IGSCC remedy early in 1988 (NUREG 0313, Rev. 2).

Commonwealth has used the MSIP procedure on a total of 333 welds at its Dresden-1 and -2, Quad Cities-1 and -2, and La Salle-1 and -2 BWRs. By the utility's best estimate, it will thereby avoid some $434 million of expense for special in-service inspections and replacement of piping. MSIP also cut the occupational radiation exposure of Commonwealth workers by about 20 person-rems for each of those avoided welds. For information on MSIP, contact E. J. Hampton at SMC O'Donnell in Pittsburgh, Pennsylvania, (412) 655-1200. ■ *EPRI Contact: Joe Gilman, (415) 855-8911, or Wylie Childs, (415) 855-2058*

Maintenance Equipment Data in Catalog Form

In addition to its program of technology workshops, evaluations, and demonstrations, EPRI's NDE Center in Charlotte, North Carolina, is serving EPRI member utilities as a clearinghouse for information on power plant maintenance equipment. In that role the center has assembled a comprehensive file of equipment information, including technical papers, NDE Center evaluations and performance data (not recommendations), and vendor literature and covering everything from nuts and bolts to remotely controlled submarines for underwater inspection.

Now the center has responded to utility interest in specific topics by compiling two new equipment guides, the *Valve Maintenance Equipment Reference Guide* and the *Remote Equipment Guide: A Compendium of Selected Types of Robotic Equipment Used in Hazardous Environments*. "These guides are a new kind of resource, impartial catalogs of the equipment available in particular areas of maintenance," says EPRI program manager Jim Lang. "They cover EPRI-developed equipment and include equipment developed by other organizations as well."

The *Valve Maintenance Equipment Reference Guide* focuses on motor-operated-valve performance testing, relief-valve testing, valve machining, valve-seat hardfacing, and miscellaneous types of valve maintenance. The guide includes specification sheets and photographs of currently available equipment.

The *Remote Equipment Guide* presents information on terrestrial and underwater remotely operated vehicles, pipe crawlers, and manipulators. An electronic database of the information in the equipment guide is currently under development. To obtain the guides, contact Ken Brittain at the NDE Center, (704) 547-6139. ■ *EPRI Contact: Jim Lang, (415) 855-2038*

Dam Safety

Concrete Gravity Dam Stability

by Douglas Morris, Generation and Storage Division

Most of the dams associated with hydroelectric plants are licensed for operation by the Federal Energy Regulatory Commission (FERC). In response to an increased national awareness of the need for a regulated dam safety program, the Code of Federal Regulations was amended to require that all licensed dams be reanalyzed for stability and safe operation every five years.

One of the loading conditions to be analyzed is the probable maximum flood (PMF). This is calculated for each dam site by using a worst-case sequence of precipitation for the drainage basin (called the probable maximum precipitation, or PMP) and a possible, but worst-case, scenario for estimating the maximum runoff into the river.

The concept of the PMF as a flood load for dams was introduced in the 1970s; therefore, almost all dams built before then are unable, in theory, to withstand that flood level. Very few remedies exist for this situation. If there is sufficient space, the spillway capacity can be increased to pass the flood around the dam. In the case of concrete gravity dams, a dam can be anchored by threading large anchor cables from the dam's crest through vertical holes. One end is grouted in mortar in the rock foundation and the other is post-tensioned at the crest. EPRI has estimated the average cost of installing anchor cables to be $2 million per dam. Figure 1, which shows a section of a concrete gravity dam, provides an understanding of the major forces affecting dam stability.

EPRI's dam research is aimed at helping utilities understand the stability of their dams under the more severe PMF loading conditions. Without this knowledge, dam owners are obliged to be overly conservative with their engineering designs and upgrading programs.

Design conservatism exists in many areas. For example, the FERC stability analysis guidelines (which reflect the design approaches of the Army Corps of Engineers and the Bureau of Reclamation) state that without adequate site-specific data to prove otherwise, the concrete should be assumed to crack under tensile stresses greater than 10% of its compressive strength; according to the guidelines, the tensile strength of the joints where new concrete was poured on old concrete might be less. No tensile strength is allowed for the bond between the concrete and the foundation (which is rock for concrete gravity dams). Regardless of the actual strength of the bond, the FERC approach assumes that the rock just below the surface has been damaged by blasting or that adversely oriented geological joints could fail. If any part of the dam goes into tension under load, then a crack must be assumed that will run horizontally until a compression zone is reached. The uncracked portion must retain the stability of the dam.

Uplift pressure is assumed to exist within a dam, at the dam-foundation interface, and within the foundation. This pressure is caused by water seepage and can have a maximum value equivalent to the pressure head of the water in the reservoir. When a crack occurs, the crack is assumed to have the maximum uplift pressure across its horizontal area commensurate with its elevation and the reservoir level.

Drains are included in dams to relieve uplift pressures. The FERC allowance for drain effectiveness depends on actual pressure measurements taken at the drain locations and on the maintenance program for drain cleaning. More significant to research studies is that unless evidence is presented to the contrary, the drains are assumed to have no effect if intersected by a crack under flood conditions.

These design assumptions compensate for a lack of knowledge about concrete cracking characteristics and an initial lack of computa-

ABSTRACT *New federal regulations adopting a more stringent flood criterion have forced reanalysis of the nation's older dams. The result is a reevaluation of many of the design assumptions that have been the basis of dam design and stability analyses for over 80 years. EPRI research is providing methods for obtaining more-accurate site measurements to characterize actual site conditions and is developing numerical modeling techniques to simulate concrete cracking and drain effectiveness. Although these studies have not yet been completed, the results are already reducing the costs required to strengthen dams.*

tional tools for modeling the interactions of forces on a dam. They also compensate for the lack of a reliable history of valid measurements.

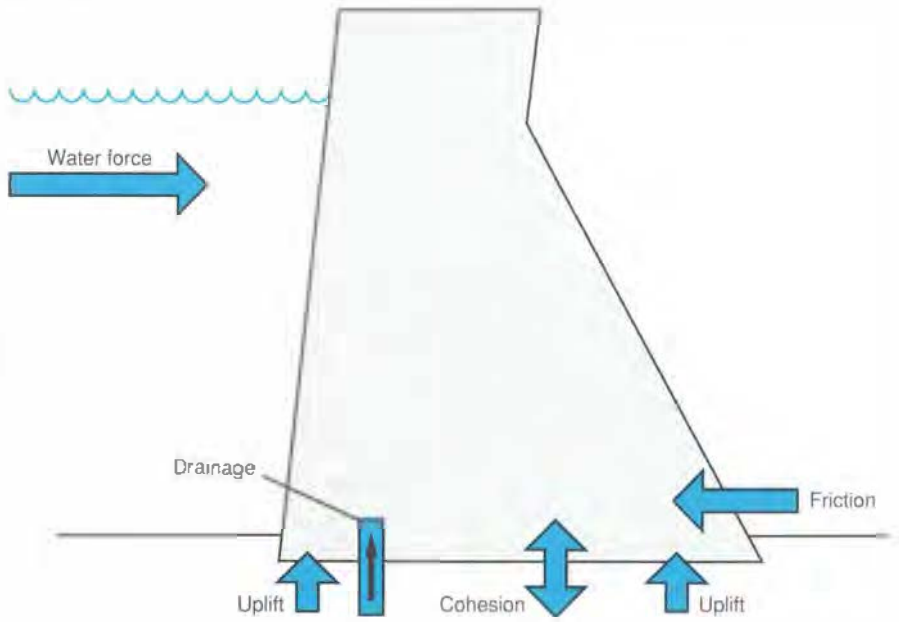
EPRI's research studies seek to develop more-accurate models of concrete cracking mechanisms, to investigate the behavior of uplift pressure and drain effectiveness for very fine cracks (10- to 40-mil aperture), to model uplift pressures in rock foundation joints, and to introduce methods of extracting credible data from existing dams for input to stability analyses. Implementation of the different methods should determine the conservatism (i.e., design margin) in any given dam and permit the application of this design margin toward meeting the PMF criterion with a minimum of additional strengthening.

Research results

The EPRI studies, which are not yet completed, include guidance for compiling site-specific measurements to take advantage of site conditions that are usually better than FERC's generic allowances. A database of stability information from 18 host dams representing older designs will be compiled to support individual submissions to FERC by showing typical ranges of strength, drain performance, and other parameters. A finite-element code based on the EPRI-supported ABAQUS code is being designed for gravity dam stability analysis to provide a convenient alternative to the overly simplistic cantilever beam approach used by most dam engineers. Laboratory investigation of the distribution of uplift pressure in concrete cracks and rock joints is under way to determine the effect of drains and different drain diameters on controlling that pressure. Finally, an analytical computer code that uses fracture mechanics as the mechanism of concrete cracking will be used to predict the length and direction of potential cracks.

EPRI has developed and field-tested detailed guidelines for the successful extraction of intact core samples of concrete and rock from existing dams. When the guidelines are followed, core samples have far fewer breaks from drilling and handling than is normally the case. Such good-quality samples, together with the recommended documentation procedures, provide excellent records of in situ conditions—records capable of supporting arguments to FERC for using higher values of material strength and better bond conditions than those in the generic case. The guide suggests videotaping the inside of boreholes and drains with a special 3-inch-diameter, remotely controlled television camera to record wall conditions and identify cracks. Methods are given for isolating these cracks to measure any inflows or outflows. This work is associated with the compilation of the stability information from the 18 sites representing a range of older dams and foundation geology.

Figure 1 Cross section of a concrete gravity dam. The weight of the concrete counters the force of the water in the reservoir. The dam is initially prevented from sliding by the cohesion of the rock-concrete bond. If that bond were broken, sliding could be prevented by the friction force of the bonding materials. Few dams have the flat base shown here; broken surface rock is cleared down to a sound foundation, creating trenches that provide additional anchoring. The uplift pressure shown is caused by water seepage in rock joints and cracks in the foundation and at the dam-rock interface.



The information obtained from mapping foundation cracks and rock joints by borehole investigations can be combined with surface observations of similar rock anomalies for input to an EPRI-developed numerical model of pressures and flows in dam foundations. The theory for that model resulted from a project to investigate the distribution of uplift pressure in very fine cracks (10 to 40 mils). The code statistically generates various hypothetical configurations of joint sets in the foundation to compensate for those that escaped mapping. The foundation model calculates and maps the uplift pressure acting on the dam for the postulated joint configurations, then automatically creates another hypothetical configuration from the same basic input data. That procedure is repeated many times until an adequate range of results has been obtained. This approach can warn the engineer of the possibility of unusually high values of uplift pressure below the dam. Such a condition would be typical of a joint set that connects the reservoir to a point in the dam base downstream of the drains.

As mentioned above, EPRI is investigating uplift pressure distribution in concrete cracks and the effectiveness of drains in reducing those pressures. A series of concrete slab models of cracks in dams has been used to test the effects of crack aperture, crack roughness, crack waviness, drain diameter, and entry water pressure on flow in a crack and the resulting pressure pattern. This information will allow the investigators to develop coefficients that characterize the parameters measured in the tests. The appropriate coefficient values

will be used to define actual conditions and, thus, dam stability. A similar approach to defining concrete crack properties by coefficients will allow the back-calculation of apparent crack size for situations where a crack has been discovered in a dam and an estimate of its possible length is required.

Crack propagation in concrete

Concrete, like ceramics, is subject to brittle fracture, but the traditional approach has been to treat concrete as if it were a ductile material. Fracture mechanics was developed to model fractures of brittle material. EPRI research is investigating how to apply fracture mechanics concepts to concrete dams so that crack propagation can be more accurately simulated.

This work has already resulted in a computer code that models cracks in the concrete mass of a dam. Testing of laboratory models is continuing in order to determine what happens when cracks intersect discontinuities, such as the dam-rock interface or geological joints in the foundation. Splitting tests have been performed on large concrete samples of different-size aggregate to obtain fracture toughness values. It was found that aggregate size did not significantly influence crack length. Further testing will determine if the shape of the aggregate is important (rounded riverbed stones versus sharp crushed rock). Other test results show that the fracture toughness of concrete increases as the crack length increases; that is, the material at the crack tip resists progressive tensile crack extension. Therefore, the uncracked material has progressively greater strength. This result suggests that existing dams have a greater capability to withstand the PMF loading than previously assumed.

By adapting a generalized finite-element analysis code called ABAQUS-EPGEN, EPRI is also providing a near-term method of more accurately calculating dam stability on the basis of the conventional strength-of-materials method. The user will not have to be familiar with finite-element analysis or the ABAQUS code to perform the stability calculation. The essential input data requirements will be the dimensions and parameters that define the dam and the foundation. The code will select the appropriate finite-element mesh and will be capable of analyzing static and dynamic load conditions. Special code features will permit sensitivity studies to be conveniently performed so that a given dam's reaction to many different conditions can be better understood and its structural weaknesses can be identified.

Probable maximum precipitation

The PMP values available from the National Weather Service (NWS) are extrapolated from actual severe storms across hundreds of miles of terrain. As a result, the PMP may be overly conservative for many specific locations. In one instance, FERC has accepted a PMP value substantially lower than the NWS value.

Given this situation, FERC has encouraged EPRI to improve the understanding of the types of extreme precipitation storms that contribute to probable maximum flood estimates. These studies are investigating weather data captured on radar and satellite plots over the last 10 to 20 years in an attempt to understand storm patterns and frequencies. These initial investigations might eventually augment the precipitation gage data that form the basis of the PMP values published by the NWS. Attempts will also be made to quantify the effect of topography on precipitation. It is hoped that the results of this research will encourage utilities to derive their own site-specific PMP values where appropriate.

Although a dam might meet all current design criteria, the expansion of local populations and their need for housing, work, and recreational facilities will vastly increase the potential and cost of downstream damage. The result will be a continuing need to assess the status of dams. The tools being developed by EPRI for realistically evaluating dam stability will not be used just once per dam but will be required to assess continually changing conditions, new regulations, and the ravages of time.

Ecological Studies

Application of Genetic Ecology to Bioremediation

by Robert Goldstein and Donald Porcella, Environment Division

Approximately a year and a half ago, EPRI's Environment Division, in cooperation with its Office of Exploratory Research, initiated research on developing a new cross-disciplinary field of science called genetic ecology. Genetic ecology is the study of how environmental (physical, chemical, and biological) factors affect the abundance and functioning (expression) of genes. It is derived from the introduction of the concepts and techniques of molecular genetics into an ecological context.

Through the application of knowledge derived from genetic ecological research, there exists the potential to develop new biotechnologies to remediate polluted sites in situ. This would be done by altering environmental factors at the sites to manipulate the genetic systems of indigenous microbiota to control specific biochemical degradation or transformation processes (*EPRI Journal*, September 1988, p. 14). Genetic ecology should not be confused with genetic engineering, which is the introduction into the field of exotic organisms that have been genetically manipulated in the laboratory.

The pollutants targeted for remediation may be either organics or metals. The prime objective for organics is complete and rapid degradation. For metals, the objective is to control

ABSTRACT *Research results support the hypothesis that an understanding of the relationships between the environment of genes and their abundance and functioning can be used to develop technologies for in situ waste cleanup. Amplification and increased expression of genes capable of mercury transformation and naphthalene degradation have been achieved in the laboratory through modification of the physical and chemical properties of their environment.*

biogeochemical cycling so as to concentrate the metal in a chemical species or physical compartment that minimizes availability and toxicity to macrobiota. For instance, in aquatic systems, the objective might be to sequester the metal in an insoluble form in the sediments or to convert the metal into a volatile form that would escape the water body.

Why genes?

What are the potential advantages of focusing an in situ bioremediation strategy on the manipulation of indigenous groups of genes instead of on indigenous microbial species? The principle being used is that one gene produces one enzyme, which in turn controls one biochemical reaction. In contrast, a single microbial species conducts hundreds of functions. Manipulation of a species hence directly affects hundreds of functions, whereas manipulation of a single gene affects only one—though, indirectly, it could affect more. Thus the genetic system is a fine-control system relative to the species population structure of the microbial community. Also, the identities of the species that are producing the target enzymes are not necessarily relevant. An optimal management strategy might be to induce the presence and expression of the target genes in all species within the indigenous microbial community. This can potentially be accomplished by stimulating natural processes of gene exchange in situ.

Further, it is assumed that since a single gene or a small number of genes has so many fewer direct linkages to the environment than a single species, the population of target genes should be less rigidly constrained by the existing environment and hence be more amenable to manipulation. The hypothesis is that, in general, a community of microbial species is more stable with respect to its species structure than to its genetic structure; that is, it is easier to alter the abundance of a single gene than that of a single species, since changing a single species is in effect changing thousands of genes. Hence minor modification of the genetic structure of an indigenous microbial community should require less environmental manipulation than modification of the species structure.

Research approach

EPRI maintains three ongoing contracts pertaining to the application of genetic ecology to bioremediation (RP8000-25, RP3015-1, and RP3015-2). The first two (being carried out by the University of California, Irvine; the University of Tennessee; the University of Arizona; Texas A&M; and the University of California, Santa Cruz) focus on developing strategies to manage biotransformation and biodegradation processes in the field. Cooperative

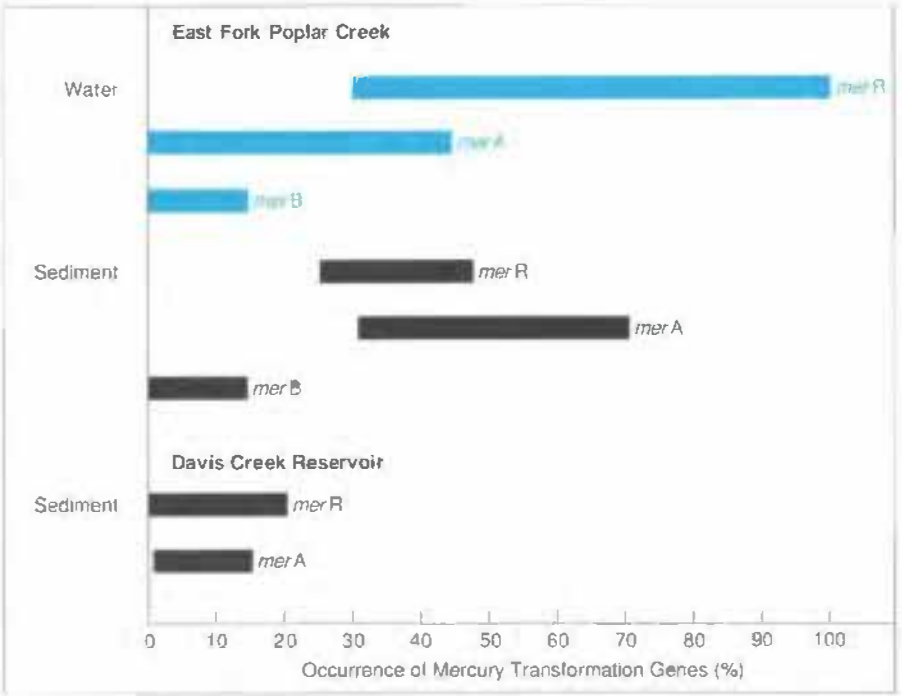
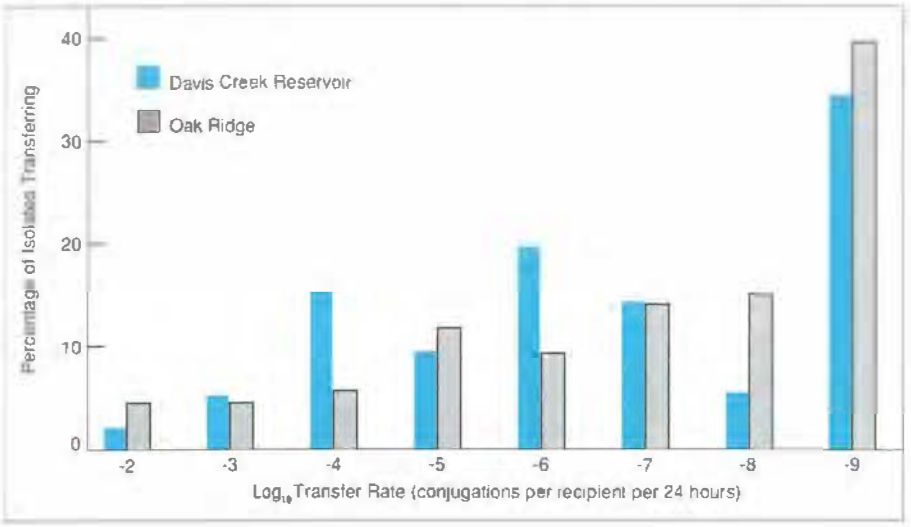


Figure 1 Percentages of bacteria isolated at two of the mercury-polluted field sites that contain different genes found on the mercury operon. The data were collected at different sampling locations and times. *Mer*R is the regulatory gene that turns the operon on and off. *Mer*A is associated with the reduction of the mercuric ion to elemental mercury. *Mer*B is associated with the demethylation of methylmercury. Some operons possess the ability to both demethylate and reduce, while others can only reduce.

Figure 2 Distribution of logarithmic conjugation (transfer) rates of the *mer* operon for bacteria capable of conjugation that were isolated at two of the mercury-polluted field sites. Not all bacteria that contain the *mer* operon possess the ability to transfer the operon.



support is being provided in this effort by Niagara Mohawk, Pacific Gas and Electric, Southern California Edison, Homestake Mining, the Wisconsin Department of Natural Resources, Oak Ridge National Laboratory, the U.S. Department of Energy, and the following other EPRI research projects: Animal Responses to Interacting Stresses (ARTIS, RP2020), Environmental Behavior of Organic Substances (EBOS, RP2879), and Health Effects of Complex Mixtures (RP2963).

The biotransformation in aquatic systems of methylmercury and the mercuric ion to elemental mercury and the biodegradation in soils of naphthalene to pyruvate and carbon dioxide have been chosen as model processes to study. These were chosen because sets of microbial genes, known as operons, that control these processes have been identified and characterized. In addition, mercury is a potential toxicant of concern to the electric power industry (*EPRI Journal*, December 1987, p. 47), and naphthalene is a representative polycyclic aromatic hydrocarbon (PAH). PAHs are of concern to the electric power industry because they are contaminants at former manufactured gas plant sites (*EPRI Journal*, July/August 1989, p. 22).

The research approach is composed of three stages. In the first stage, water and sediment samples are collected at mercury-contaminated field sites and soil samples are collected at naphthalene-contaminated sites. The ability of the bacterial community at these sites to degrade naphthalene and transform mercury, the abundance of the bacterial operons present that control these processes (target operons), and the potential to amplify the number of target operons are measured.

In stage two, microcosm experiments are conducted in the laboratory, where environmental factors are varied under controlled conditions to determine how the rate of expression of target operons can be maximized. Expression is the product of the density of target operons and their expression efficiency (the fraction of target operons that are functioning). The fact that an operon is present does not mean that it is functioning.

Expression can be increased by increasing either the abundance of target operons or the expression efficiency, or both. Both abundance and efficiency are functions of environmental properties; hence, it should be possible to manipulate abundance and expression in a predictive manner through alteration of the environment. Hypotheses to be tested in the microcosms regarding the dependency of expression on environmental variables can be suggested by correlation of the results from stage one with site environmental data.

The results of stage two are used to devise in situ remediation strategies that are then tested in environmental enclosures at field sites during stage three.

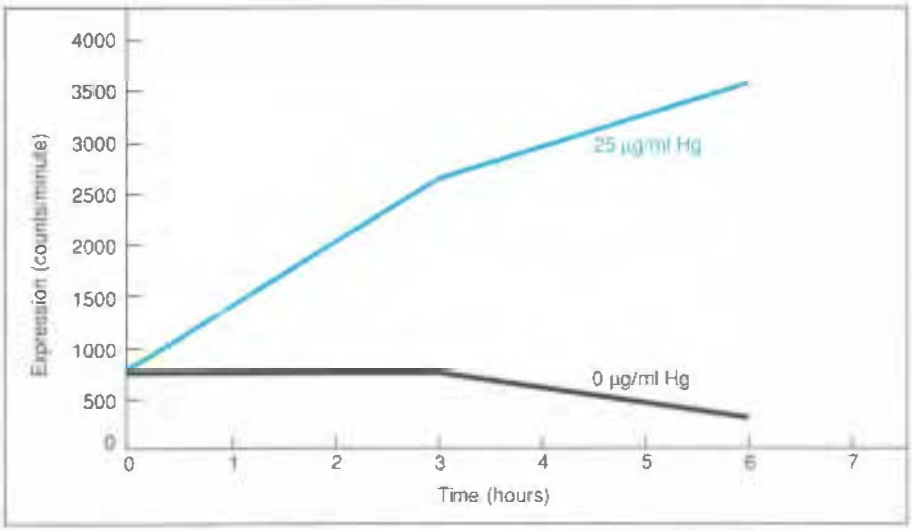


Figure 3 In the laboratory, expression of the *mer* operon in the bacterial species *Pseudomonas stutzeri*, as measured by the amount of *mer* operon messenger RNA (ribonucleic acid) present, increases in response to the addition of mercuric chloride. Values given are in radiation counts per minute per 5 micrograms RNA at 4°C.

Results

Although the research is only in its early stages, a wide variety of intriguing results have already been achieved.

Operons capable of mercury biotransformation and naphthalene biodegradation have

been identified at the mercury- and naphthalene-polluted field sites, respectively (Figure 1). Bacteria isolated at the mercury-polluted sites were shown to have the ability to transfer to other bacteria, by conjugation, copies of the operon that transforms the mercuric ion to elemental mercury. Conjugation is a natural process whereby two bacterial organisms come adjacent to one another and genetic material is transferred from one (the donor) to the other (the recipient). The measured conjugation logarithmic rates, which are calculated in terms of the fraction of the recipient population to which the operon is transferred in a 24-hour period, range over seven orders of magnitude (Figure 2). Naturally occurring rates previously reported in the literature tended to be a millionth or a ten-millionth. In this study, rates as high as a hundredth were measured. Since densities of recipients in the environment may be as high as 100 million per gram of dry sediment, the total number of transfers occurring in a 24-hour period could be as high as one million per gram.

In the laboratory, abundance and expression have been increased for mercury biotransformation operons possessed by bacteria isolated at the field sites. These increases were accomplished by manipulation of temperature and of mercuric chloride concentrations in the growth medium. It has been demonstrated that expression can be enhanced at temperatures as low as 4°C through the addition of mercuric chloride (Figure 3). The potential significance of this result is that although it is commonly assumed that transformation rates are very slow at low temperatures, there appears to exist the potential to enhance detoxification rates at low temperatures through the modification of the chemical environment. This principle would have applicability to the development of in situ management strategies for cleanup sites that have cold winters.

It has also been demonstrated in the laboratory that amplification and expression of the naphthalene-degrading genes can be increased by the addition of salicylate, a nontoxic intermediate in the degradation pathway. It has commonly been observed that detoxification rates can be increased by the addition of the toxic substance itself, as was done with mercury in the experiments described above. But in actual cleanup it would be undesirable to add the substance eventually to be removed. It is therefore significant to have demonstrated that degradation can be enhanced by the addition of a nontoxic intermediate.

In summary, results to date have been highly promising in that they have been consistent with the hypothesized conceptual framework upon which the research is based; that is, microbial genes capable of biodetoxification are present at contaminated sites, and the rates of biodetoxification potentially can be enhanced by increasing the expression rates of these genes through manipulation of environmental factors.

Commercial Program

National Electrical Code Revision

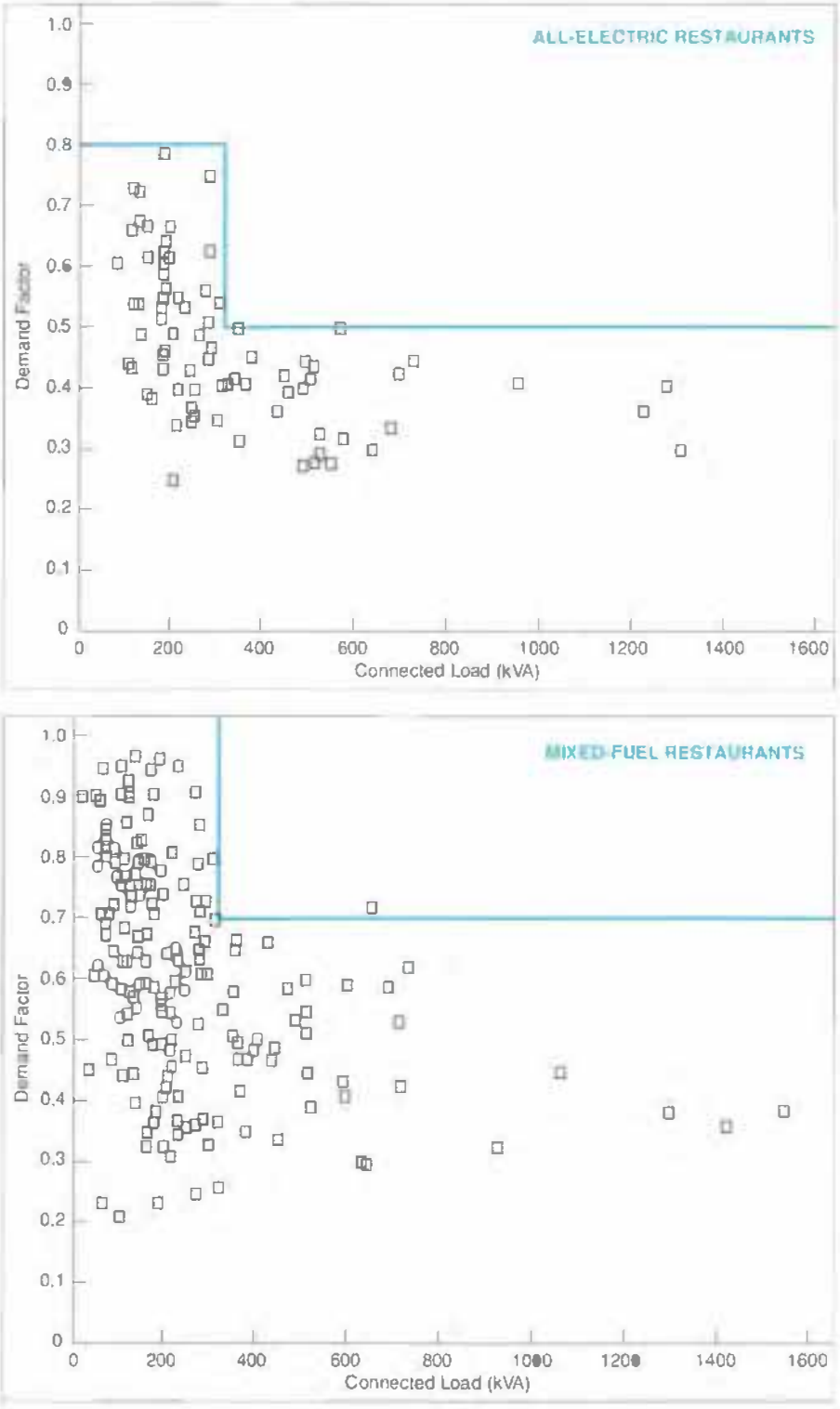
by Karl Johnson, Customer Systems Division

In the 1950s and 1960s with the help of 40 utilities, Orin Zimmerman, now at EPRI, introduced the concept of diversity into the National Electrical Code. Drawing on data from over 100 restaurants, Zimmerman proved to the code panel that as the number of cooking appliances in a restaurant increases, the peak demand for power relative to total connected load decreases. Demand factors (peak-demand load divided by total connected load) decrease as connected loads increase. In simplified terms, as the number of electric appliances increases, the probability that all of them will be cycling on at the same time decreases.

In 1987 an EPRI-sponsored study of Department of Energy raw data from the Project on Restaurant Energy Performance (PREP) found that in spite of Zimmerman's earlier work, restaurants built to the current code specifications still had surprisingly large amounts of excess capacity. Careful analysis of the seven PREP restaurants found that service entrances were 24–55% oversized. EPRI contacted the

ABSTRACT *The National Electrical Code has just been revised to allow smaller service entrances and main distribution panels in new restaurants. Where the new provisions are applicable, first-cost savings can be significant, improving the market position of all-electric restaurants. This is the first optional calculation method approved for the code since 1973.*

Figure 1 Demand factors (the peak-demand load in a restaurant over the previous year, divided by total connected load) were computed for 262 restaurants from data supplied by EPRI member utilities and other industry participants. Demand factors never exceeded 0.5 in all-electric restaurants with connected loads above 325 kVA, nor did they exceed 0.8 in similar facilities with connected loads below that. Demand factors were higher in mixed-fuel restaurants.



National Restaurant Association (NRA), one of the original sponsors of the study, to discuss these findings. It was agreed that panel sizes generally appeared to be too big and that the matter merited further study. With the help of the NRA, the Edison Electric Institute (EEI), and the Electric Light and Power Group (utility specialists on the National Electrical Code), EPRI initiated a study of 100 restaurants.

Restaurant data

With EPRI's technical guidance, a contractor was hired to collect and analyze restaurant data from EPRI and EEI member utilities. Over 20 utilities responded. On the basis of data from the initial 100 restaurants, a proposal was prepared and submitted to the code panel. The proposal sought to extend the concept of diversity—originally formulated by considering cooking and water-heating equipment only—to the whole restaurant, including lighting, cooling, refrigeration, and other electrical equipment. This proposal was rejected in an 11-to-1 vote because it was felt that more data were needed to support this change.

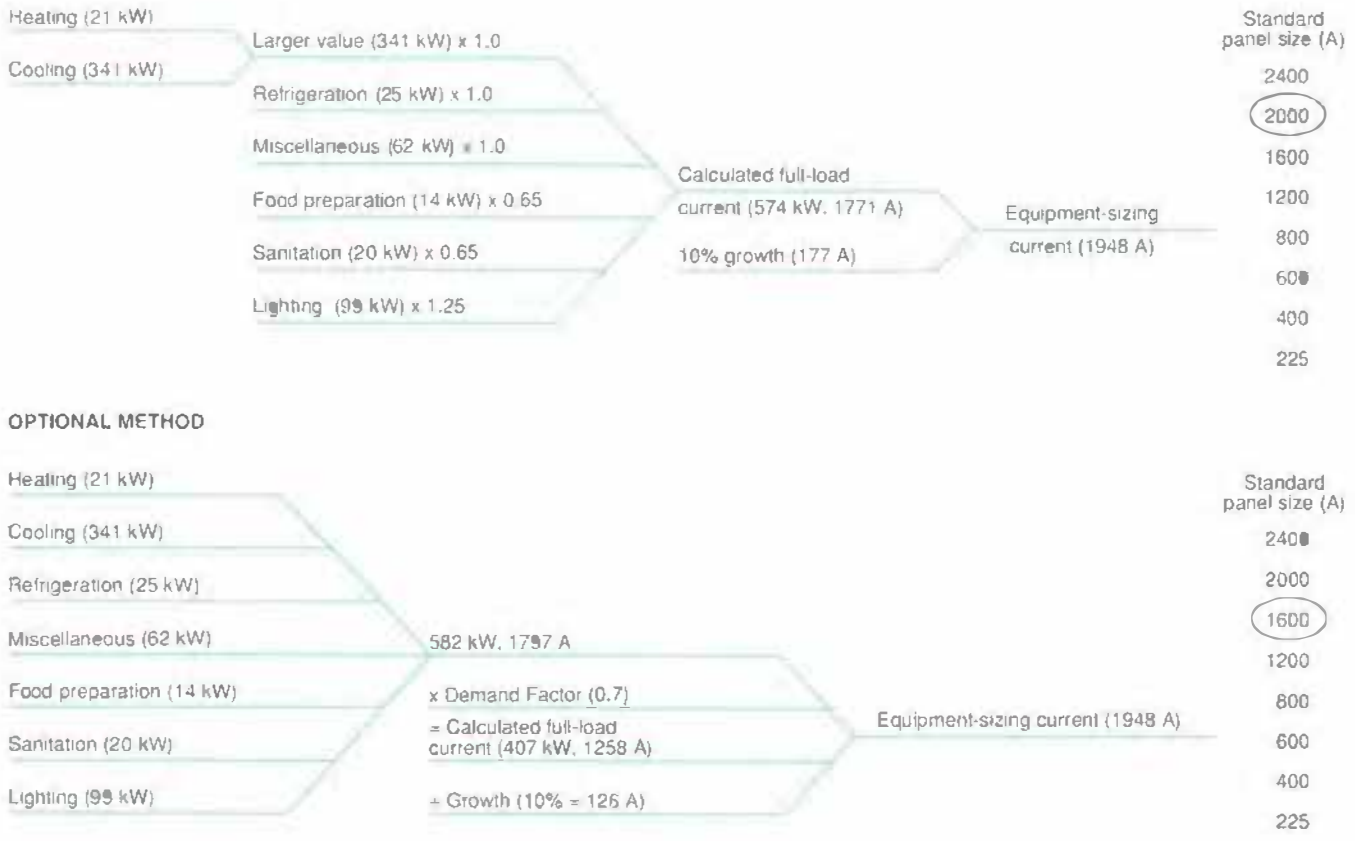
With the help of the sponsors and another 20 member utilities, EPRI expanded the restaurant database to 262 all-electric and mixed-fuel restaurants over the next year. Only one restaurant out of the 262 was found to fall (slightly) outside the demand factors proposed by EPRI and the NRA in their original proposal (Figure 1).

Armed with this expanded database, which now covered all climate regions and all major restaurant types, the project manager and the contractor called on the members of the code panel to identify and address their concerns. During this process a sample calculation was developed to illustrate the mechanics of the new, optional method. Because safety is the code panel's principal concern, the example calculation selected was for the worst-case restaurant in the database—restaurant 256, the one point that fell outside the proposed demand factors.

Optional method

The previous code required more steps than the new method does to arrive at a standard panel size (Figure 2). For example, to calcu-

Figure 2 Example calculation of panel size for restaurant 256 under the previous code and under the new, optional method. Previously, demand factors could be applied only to food preparation and sanitation equipment in new restaurants. Under the 1990 National Electrical Code, demand factors can be applied to the entire connected load for the restaurant, thus greatly simplifying the calculation and often reducing the size and cost of service entrances and main distribution panels.



late the panel size for restaurant 256 by the traditional method, demand factors are applied to food preparation, sanitation, and lighting loads. Actual connected loads are also included. On the basis of the computation process under the previous code, a 2000-A panel would be required for restaurant 256.

Under the new, optional method (1990 NEC Article 220-36), all the electrical loads in the building are added, and then one demand factor is applied. For facilities with connected loads up to 325 kVA, the all-electric demand factor is 0.8 and the mixed-fuel demand factor is 1.0. For those with connected loads over 325 kVA, the all-electric demand factor is 0.5 and the mixed-fuel demand factor is 0.7. Assumptions used under the old method to account for growth are also applied under the new method. Using a growth factor of 10%, a designer would select a standard panel size of 1600 A under the new method.

According to actual billing records, the highest demand recorded in restaurant 256 over the previous year was 1292 A, and the average monthly demand was 753 A. Thus, even in the worst case, safety would not have been compromised and nuisance tripping would have been extremely unlikely with a 1600-A panel.

After reviewing the technical data and the various illustrations provided, the code panel accepted the proposed optional method at their meeting in November 1988. Their decision was confirmed by the full National Fire Protection Association in May 1989. The 1990 National Electrical Code was published August 7, 1989, and will begin to be accepted by local and regional jurisdictions early in 1990.

EPRI, in cooperation with the NRA, is now preparing a detailed analysis of the cost reductions that will be likely to result from implementing the new code. Estimates range up to a few thousand dollars for smaller facilities, and savings will probably be even greater in larger ones. Because of the higher connected loads in all-electric facilities, savings will be higher for these restaurants than for mixed-fuel restaurants. These savings should help to remove one of the classic market barriers to all-electric restaurants.

Various technology transfer documents are being developed at EPRI and the NRA. An announcement of the code change was made to local code enforcement officials through the

NRA publication *Update* in September 1989. A press conference and articles in various trade publications are scheduled for early 1990, when the code takes effect. EPRI is also working on a technical brochure, to be published in 1990.

Customer service representatives should begin informing customers who are planning new restaurants about this important code change. A workshop entitled "Applying the Optional Method for Sizing Service Entrances in New Restaurants" is to be given at the EPRI Foodservice Symposium in February 1990.

The success of this campaign to change the National Electrical Code may well be a model for other activities in which the electric utility industry, with technical support from EPRI, can identify customer needs and reach national solutions beyond the scope of any single utility working alone. In addition, the good working relationships established with trade allies, like the NRA, and EEI create the possibility for even more customer service in the future.

Quality Engineering Activities

NCIG Update

by Warren Bilanin, Nuclear Power Division

The organization known as NCIG, under the sponsorship of EPRI, provides an effective forum for the transfer of technology among member nuclear utilities. With the completion of its first task in 1985, establishing visual weld acceptance criteria, NCIG proved its effectiveness and ability to provide timely and cost-effective solutions to industry construction problems. The industry recognized the value and applicability of some of the criteria not only for plants under construction but also for the modification and repair of operating plants.

Formerly the Nuclear Construction Issues Group (established in 1984), NCIG has undergone a transformation in the past years. Not only has the name changed, but the focus of the organization has been more clearly defined and an organizational charter has been established and ratified by unanimous consent of the members. The name, which now consists only of the letters NCIG, is no longer an acronym for Nuclear Construction Issues Group. The name and organizational focus were changed to better reflect the engineering and operational nature of the work supporting the member utilities. Support issues affecting the nuclear utilities and the industry as a whole have been identified, and task plans have been developed, approved by the members, and implemented. EPRI has issued a number of reports to help standardize the approaches to problems and guide member utilities in the solution of these problems (Table 1).

Objectives

The NCIG charter established the following objectives.

- Develop a common approach to the resolution of technical issues related to nuclear power plant physical facilities that is acceptable to both the nuclear industry and the NRC.
- Provide a means of sharing information and concerns with professional organizations and societies for purposes of obtaining their involvement and support in the resolution of NCIG issues.
- Provide continuing support to the documents developed by NCIG to maintain consistency with industry changes until such time as these documents are incorporated, if appropriate, into established consensus standards.
- Support the needs of the NCIG members and pursue those technical tasks that have a general application to the nuclear industry.

ABSTRACT *To meet the technical challenges of plant operation, maintain conformance with licensing requirements, and contribute to industry standards, a number of EPRI member nuclear utilities have joined forces with EPRI in a series of research and technology transfer efforts under the organizational name NCIG. As manager of the NCIG program, EPRI provides assistance at all stages, from task identification through information dissemination. After half a decade of operation the organization's activities continue to provide useful solutions to problems affecting nuclear plants.*

- Provide a forum for sharing information on nuclear issues for concerned organizations, i.e., utilities, constructors, professional organizations and societies, industry, and the NRC.

NCIG's activities are reviewed by the Nuclear Management and Resources Council (NUMARC) and coordinated with the Institute of Nuclear Power Operations (INPO) and other industry organizations to obtain recommendations and comments as appropriate. All tasks undertaken by NCIG are approved by the NCIG membership as well as the EPRI advisory structure.

NCIG membership and EPRI's role

The participation of the NCIG member utilities has been, and will be, the key to the continued success of this organization. Approximately 30 member companies provide support to NCIG. NCIG members are utilities that accept and fund one or more NCIG tasks or make a substantial technical contribution to the success of a task. An NCIG task is a work effort with a well-defined objective that has been accepted by the membership. Each completed task becomes the subject of a report. NCIG members participate to varying degrees in the successful completion of the tasks. All EPRI members, however, have derived benefits from NCIG's solution of engineering, technical, quality assurance, and administrative problems.

EPRI manages the program for NCIG. Program management responsibilities include technical and administrative assistance in identification and development of task activities; contract administration; and provision of technical and financial status reports and schedules to the NCIG membership.

As appropriate, representatives of architect-engineers, constructors, specialty consultants, equipment suppliers, and codes and standards organizations may be invited by the NCIG chairman to participate in NCIG general meetings and in the technical development and performance of NCIG tasks.

Status of some current tasks

The TERI guideline (Technical Evaluation of Replacement Items, NCIG-11), the most recently completed task, permits utilities to use a systematic technical evaluation process to ensure that replacement items procured for nuclear power plants are equivalent to original items. The report on this task was published in December 1989.

A related report describing the acceptance and dedication process for commercial-grade items (CGI), EPRI NP-5652 (NCIG-07), was issued in June 1988.

NCIG's Guidelines for the Repair of Nuclear Power Plant Safety-Related Motors (NCIG-12) will permit utilities to have capable repair shops repair all classes of safety-related electric motors, either through the extension of the utility's own quality assurance program during repair, or through acceptance and dedication of the motor as safety-related equipment following repair as a commercial-grade item. The report for this task will be issued in the first quarter of 1990.

Guidelines for Establishing, Maintaining, and Extending the Shelf-Life Capability of Limited-Life Items (NCIG-13) will also provide the user with recommendations for packaging and storing these items, along with guidance for the evaluation of items with expired shelf lives. The report on this task is scheduled for release in the first quarter of 1990.

NCIG's Procedure for Seismic Evaluation and Design of Small-Bore Piping (NCIG-14) provides a rational, consistent, and simplified basis for the seismic design and evaluation of small-bore piping. By allowing more-flexible systems and thus reducing thermal stress, this procedure will help increase reliability of piping and reduce plant piping congestion and cost. The report is scheduled to be issued by mid-1990.

Guidelines for Assuring the Quality of Procured Items (NCIG-15) will assist in ensuring the technical adequacy of procured items by emphasizing the importance of establishing technical and quality requirements up front in procurement documents and also in procedures used for inspection at the time of receipt. Because of the complexity of this subject, the draft report on this task has undergone several reviews and is currently scheduled for issue in the first quarter of 1990. A companion EPRI/NCIG document on the task Guidelines for Performance-Based Supplier Audits (NCIG-16) is also scheduled for release at the same time.

As part of the EPRI/NCIG transfer of technology, four joint CGI/TERI training seminars have

Table 1
EPRI/NCIG REPORTS

EPRI Report Number	NCIG Task Number	Title
NP-5380, Vol. 1	01	Visual Weld Acceptance Criteria—Visual Acceptance Criteria for Structural Welding at Nuclear Power Plants
NP-5380, Vol. 2	02	Visual Weld Acceptance Criteria—Sampling Plan for Visual Reinspection of Welds
NP-5380, Vol. 3	03	Visual Weld Acceptance Criteria—Training Manual for Inspectors of Structural Welds at Nuclear Power Plants Using the Acceptance Criteria of NCIG-01
NP-5638	04	Guidelines for Preparing Specifications for Nuclear Power Plants
NP-5639	05	Guidelines for Piping System Reconciliation
NP-5640, Vols. 1 and 2	06	Nuclear Plant Modification and Design Control: Guidelines for Generic Problem Prevention
NP-5652	07	Guideline for the Utilization of Commercial-Grade Items in Nuclear-Safety-Related Applications
NP-5653, Vols. 1 and 2	08	Guidelines for the Content of Records to Support Nuclear Power Plant Operation, Maintenance, and Modification
NP-6200	09	A Performance-Based Selective Inspection Process
NP-6295	10	Guidelines for Quality Records in Electronic Media for Nuclear Facilities
NP-6406	11	Guideline for the Technical Evaluation of Replacement Items in Nuclear Power Plants

been scheduled. The first was held in December 1989 in Orlando, Florida. The remaining three will be held in February 1990 in Newport Beach, California, in March 1990 in Chicago, Illinois, and in April 1990 in Charlotte, North Carolina. These training seminars will consist of classroom-style lectures with question-and-answer sessions. Smaller groups will hold roundtable discussions and workshops using examples and case studies from the industry.

The positive results of NCIG's programs are being felt throughout the nuclear industry. As long as EPRI utility members continue to support NCIG tasks, and the results of the tasks provide practical solutions to problems affecting nuclear power plants, the nuclear industry will benefit. Future tasks are currently being developed by EPRI/NCIG utility members.

Delivery

Automated Distribution

by Thomas Kendrew, Electrical Systems Division

Although electric utilities may be the largest industrial users of real-time data, the sharing of those data among various elements of a utility network is still rudimentary. Most computers and communications systems used in transmission and distribution operations were designed to perform only specific functions, such as load control or supervisory control and data acquisition (SCADA). It is rare for all the components of these systems to come from the same vendor and to have compatible interconnections or standard communications protocols. As a result different systems usually have only a limited ability, or no ability, to communicate with each other, thus hindering integrated operation.

An automated distribution system provides a way of connecting all the components of a utility's operational distribution system into a single control and communications network. The potential benefits of such integrated systems are striking. More than 40 distinct functions can be centrally automated (e.g., see Table 1). EPRI studies indicate that, through the improved productivity and remote monitoring made possible by automated distribution, utilities nationwide could reduce their current annual $5 billion operation and maintenance budget by at least $250 million.

Single functions justify installation

Automated distribution systems have the potential to become the data highways for a segment of utilities' data requirements in the not-too-distant future.

Even today, some utilities are discovering that installation of currently available automated distribution systems can be justified economically on the basis of a single function. One example is the new, "smarter" substation. Today's microprocessors can operate in the harsh environment of a distribution substation and, if so ordered, make operating decisions and issue commands. In particular, these microprocessors can provide far more automation than existing SCADA systems, which provide very little knowledge of the distribution substation, and none of the system beyond the substation feeder breaker.

During a persistent fault condition with a feeder lockout, for instance, a dispatch operator must make some decisions about the fault conditions on the basis of intimate knowledge of the distribution system. Before any decisions are made, the operator must analyze operating maps of feeder routings. When the feeder route is identified, an emergency repair crew is contacted and feeder patrolling starts. After the fault is located and isolated, power is restored to other, unaffected areas, usually through manual circuit switching.

Such restoration requires immediate interaction between the dispatch operator, two or

ABSTRACT *The remote operation and coordination of utility distribution components is capable of providing annual industry savings of at least $250 million. EPRI studies indicate that automated distribution systems using expert system technology can automatically make operating decisions, coordinate components, issue commands, and provide real-time operating data. EPRI is currently sponsoring two full-scale demonstrations of automated distribution systems. A project with Texas Utilities Electric demonstrates a distributed architecture; the second project, at Carolina Power & Light, will demonstrate a large-scale integrated system using a more centralized architecture.*

three databases, and field personnel. The distribution dispatch center may have information available concerning the loading and availability of backup feeders—again through databases (maps, logs, etc.)—and the dispatch operator will use this information to determine whether a switch can be closed to pick up load for an isolated part of the faulted feeder. After restoration of service to all unaffected zones of a faulted feeder, which takes an average of about three hours, work can finally begin on the faulted area.

The preceding example outlines the required response to a single-point utility system fault and the subsequent measures necessary to restore customer service. During a major storm, the complexity of this response may increase by one or two orders of magnitude, depending on the size of the storm area and the extent of the utility itself. Under such conditions, a system operator must prioritize outage reports for a step-by-step investigation of feeders, which will inevitably result in longer outages for some customers.

Simulating operator decisions

Automated distribution systems have the capability of performing the aforementioned operations automatically, using the same techniques that an operator uses. The difference is that the fault isolation and service restoration are done at the substation level by microprocessors that have been programmed to react as an operator would. A substation microprocessor can also call on different databases to clear a fault and will queue up multiple faults, clearing them on a previously established priority basis. After a fault has been cleared, the microprocessor will call the dispatch center and report what has happened. With an automated distribution system, restoration may take minutes instead of hours.

Although the scenario described above touches on only one capability of an automated distribution system, such systems using expert system technology are capable of a full range of operation without human intervention. Automated systems will have digital protection capability far beyond the ability of today's conventional systems. Digital protection can also be adaptive (to provide better protection) and can have several subfunctions built in—for example, time overcurrent and instantaneous overcurrent, automatic reclosing, underfrequency protection, breaker backup, sync check, and diagnostics. This capability provides more functions in less space at lower cost.

System load management tool

Automated distribution systems can also aid in load management, balancing load between substation transformers and allowing for better utilization of transformer capacity. In this way, an unattended distribution substation could be considered "attended" through the use of an on-site microprocessor. With the on-site microprocessor, load can be transferred within minutes and power transformers can be loaded to full nameplate rating—not to 50%, as some are now—to allow for the failure of an adjacent transformer. This capability can defer capital investments for additional transformer capacity and produce major savings.

An integrated voltage and VAR control function can also produce large savings by controlling losses and improving voltage control. This function alone can often pay for the automated distribution system. Remote meter reading and load control are also possible. In fact, the list of automated distribution system capabilities could describe more than 150 programmable functions.

Because of its power and flexibility, automated distribution is much more than just a communications or control system; it is true automation, in which software capability actually replaces the operator in some routine utility operations.

Because of their ability to interconnect systems or databases that store data in many forms through a standardized communications system, automated distribution systems offer other utility disciplines broader capabilities. Utility planners are now looking at specific automated installations that allow them to reconfigure their systems in ways that reduce the need for redundancy, defer construction of costly facilities, and maintain reliability with reduced resources. Automated distribution is therefore just as attractive to the designer as it is to the operator.

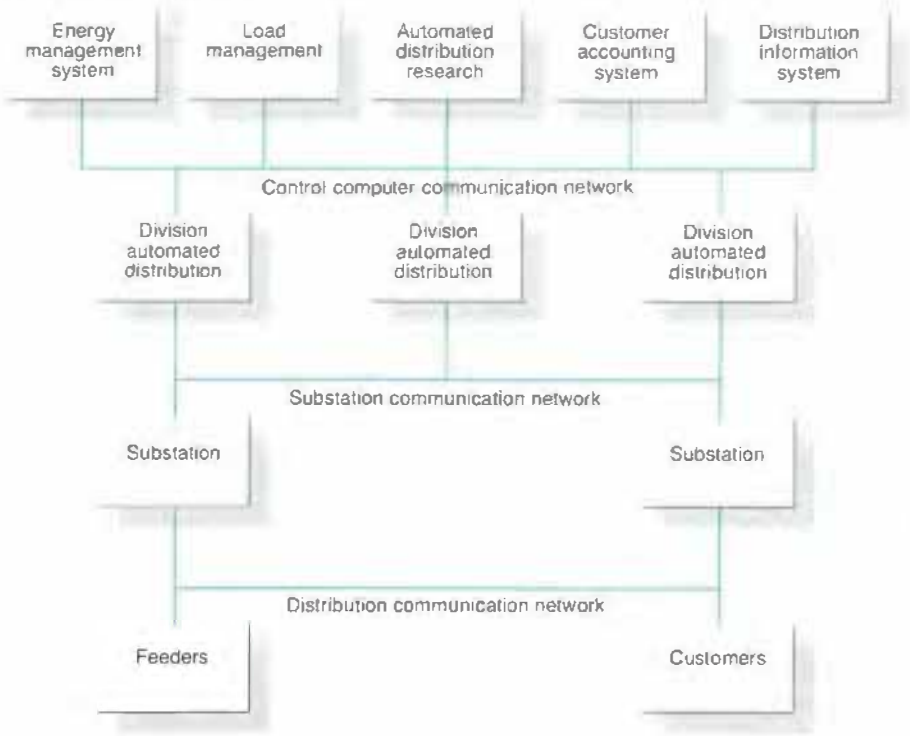
Table 1
APPLICATIONS FOR AUTOMATED DISTRIBUTION

Automatic control
Bus sectionalizing
Feeder deployment, switching, and automatic sectionalizing
Integrated voltage and VAR control
Substation-transformer load balancing
Cold load pickup on feeders
Manual control
Distribution dispatch center/SCADA interface
Data acquisition and processing
Analog data freeze
Data monitoring
Data logging
Interface
Distribution communications interface
Protection
Automatic reclosing
Bus fault protection
Instantaneous overcurrent
Time overcurrent
Substation transformer protection
Underfrequency protection
Load management
Load control
Remote service connection, disconnection
Pass-through commands
Remote metering
Load survey
Peak demand metering
Remote meter programming
Tampering detection

Automated distribution features

The main component of an automated distribution system is the communications system. The central computer must be able to receive input from remote sources, process data, and transmit instructions back to those sources or

Figure 1 Concept of integrated utility system. An automated distribution system uses extended local area network concepts and appropriate communication protocols to address the requirement for transparency to the user.



substations. This central computer and database must also be addressable in a higher-level language so that the software patched into the system from remote databases is indifferent to the location or format of the incoming data. The system must convert information stored in a variety of forms, such as maps, text, and diagrams, and pass the information from network to network as requested either by a microprocessor or at a human interface (Figure 1).

Installation of an automated distribution system also establishes a valuable interface between the utility and the customer. This will allow the connecting and disconnecting of customer loads, automated billing and payments, and direct communication between utility and customer. Automated distribution can also offer greater reliability to customers and facilitate a more economical use of a utility's resources.

Demonstration projects

The degree of compatibility between the automated distribution structure and a utility's organizational structure is a major factor in determining the success of the automated distribution system. Automation should be used to enhance the productivity of an operation; this may be difficult to accomplish if the system itself is at odds with the structure of the company. Changes can be made in a utility's organizational structure, but the chances of successful integration of automated distribution will be greater if radical changes in the organizational structure are not required.

Such organizational issues, as well as many other practical concerns involved in the installation of automated distribution systems, can best be addressed through field demonstration. EPRI is currently in the testing phase of such demonstrations in Texas and North Carolina. At Texas Utilities Electric in Fort Worth, a General Electric system is monitoring a single substation and three feeders, including digital protection. The system is on-line and is capable of complete automatic control of part of the utility's system.

A Westinghouse automated distribution system has been shipped and is being installed on Carolina Power & Light's system. Automated distribution will integrate three substations and their feeders. In addition, it can transfer load between substations to balance the load, and it can control individual loads and read meters.

Both systems can isolate and locate faults, regulate voltage, and control VAR flow.

Future plans

As utility loads grow, utility systems simply become more sophisticated; the large amounts of data necessary to operate these systems correctly could become unmanageable. Computerized distribution systems are well suited to tackle the challenges that are being created by today's sophisticated systems. Automation demonstration projects are ensuring that, as the need develops, such systems will be ready for incorporation into the distribution operations of both large and small utilities.

New Contracts

Project	Funding / Duration	Contractor / EPRI Project Manager
Business Management		
Effects of Fuel Switching on Gas Market Risks (RP2369-43)	$50,000 8 months	Energy Ventures Analysis Inc. / *J. Platt*
Utility Fuel Oil Market Trends (RP2369-61)	$52,400 6 months	The Pace Consultants Inc. / *H. Mueller*
Customer Systems		
Establishment of Iron Electrode Production (RP2415-12)	$248,000 15 months	Eagle Picher Industries Inc. / *R. Swaroop*
Cool-Storage Technology Development (RP2732-30)	$58,100 17 months	Mackie Associates / *R. Wendland*
Building Energy Systems Simulation Tool (RP2983-5)	$207,300 14 months	Syska & Hennessy Inc. / *K. Johnson*
Electrical Systems		
Real-Time Phasor Measurements for Improved Monitoring and Control (RP1999-12)	$110,100 22 months	Virginia Polytechnic Institute / *R. Adapa*
Geomagnetically Induced Current Investigations (RP2115-23)	$137,900 12 months	Minnesota Power & Light Co. / *B. Damsky*
Effects of Geomagnetic Disturbances on Electrical Power Transmission Systems (RP2115-24)	$53,800 12 months	Georgia Tech Research Corp. / *M. Rabinowitz*
Small Power System Performance With High Windfarm Penetration (RP2473-40)	$70,100 3 months	Power Technologies Inc. / *D. Curtice*
Magnetic Field Research at the High-Voltage Transmission Research Center (RP2942-6)	$722,600 18 months	General Electric Co. / *G. Rauch*
Diagnostic Alarm Processing (RP2944-4)	$236,000 15 months	Energy Control Consultants Inc. / *D. Curtice*
Practical Aspects of Power System Restoration (RP3104-1)	$476,900 23 months	Philadelphia Electric Co. / *C. Frank*
Monitoring System for Lead-Acid Cell Station Batteries (RP4000-9)	$354,600 12 months	Spectra Technologies Inc. / *R. Nakata*
Advanced Graphics Display Capability for Power System Monitoring and Control (RP4000-13)	$90,800 24 months	University of Missouri at Rolla / *R. Adapa*
Inclusion of Transmission Reliability Costs in Real-Time Pricing Decisions (RP4000-14)	$233,500 35 months	University of Wisconsin / *R. Adapa*
Parallel Computer Architecture and Systems for Real-Time Power System Applications (RP4000-15)	$106,900 24 months	University of Alabama / *D. Maratukulam*
Evaluation of the Energy Function Method Software for Dynamic Security (RP4000-18)	$99,900 14 months	Macro Corp. / *M. Lauby*
EPRIGEMS Module—Cable Ampacity (RP7909-2)	$69,900 7 months	Power Technologies Inc. / *D. Sharma*
Sensors and Advanced Trenching Equipment for Installation of Transmission Cable (RP7910-6)	$2,500,000 51 months	Battelle Memorial Institute / *T. Rodenbaugh*
Environment		
FASTCHEM Applications and Sensitivity Analyses (RP2485-15)	$264,900 18 months	Stanford University / *D. McIntosh*
Epidemiologic Study of Nuclear Utility Workers—Pilot Phase (RP2920-2)	$231,400 18 months	New York University Medical Center / *L. Kheifets*
Impacts of Climatic Change on Terrestrial Ecosystems (RP3041-4)	$48,900 9 months	Science and Policy Associates Inc. / *L. Pitelka*
Generation and Storage		
High-Concentration Photovoltaic Module Data Collection, Quality Assurance, and Reporting (RP2948-16)	$96,900 11 months	New Mexico State University / *J. Bigger*
Superconductivity Energy Storage (RP2988-1)	$822,200 11 months	Ebasco Services Inc. / *R. Schainker*
Conceptual Design for Town Gas Site Mobile Cleanup Unit (RP2991-3)	$190,500 6 months	The Mill Creek Company / *C. Kulik*
Fabrication and Startup of a Bench-Scale Catalyst Testing Facility (RP3084-8)	$121,700 10 months	Fossil Energy Research Corp. / *J. E. Cichanowicz*
RAM Evaluation of Gas Turbine NO_x Control Technologies (RP3032-1)	$143,100 8 months	Pickard, Lowe and Garrick, Inc. / *H. Schreiber*
Pseudopotential Calculations Relevant to the Staebler-Wronski Effect (RP3079-1)	$146,500 35 months	Iowa State University of Science and Technology / *T. Peterson*
In Situ Solvent Extraction of Tars (RP3072-2)	$285,000 34 months	Carnegie-Mellon University / *M. McLearn*
Transportable Pulse-Jet Pilot Baghouse (RP3083-1)	$193,200 9 months	Howden Environmental Services, Inc. / *R. Chang*
Fabric Filter Pilot Plant Operation and Maintenance (RP3083-2)	$75,300 7 months	Southern Company Services Inc. / *R. Altman*
Composting Study for Coal Tar Wastes Bench-Scale Demonstration (RP3119-1)	$288,200 23 months	Michigan Biotechnology Institute / *S. Yunker*
Characterization and Reconstruction of Coal-Gasifying Mixed Cultures (RP3119-2)	$286,400 36 months	Arctech Inc. / *S. Yunker*
Conductive and Magnetic Shielding Phenomena in High-Temperature Superconducting Machines (RP3149-2)	$82,000 13 months	University of Wisconsin / *D. Sharma*
Nuclear Power		
Erosion-Corrosion Single- and Two-Phase Flow Tests (RP2420-72)	$319,000 14 months	Siemens / *V. Chexal*
Preionized Gas Electrical Evaluation of Unshielded Power Plant Cable (RP2614-45)	$69,700 10 months	University of Connecticut / *G. Slifer*
Pulsed Energy Surface Alloy Modification (RP2614-49)	$54,700 8 months	Failure Analysis Associates / *L. Nelson*
Electrochemical Ion Exchange for LOMI (RP2614-50)	$100,200 10 months	Bradtec Ltd. / *C. Wood*
Solid-State Fusion Experiments (RP2614-52)	$300,100 7 months	Stanford University / *J. Chae*
Corium Concrete Interactions in a Stratified Geometry (RP2636-5)	$55,900 15 months	University of Wisconsin / *B. Sehgal*
Corium Coolability Scoping Test (RP2636-6)	$75,000 6 months	Argonne National Laboratory / *B. Sehgal*
Analysis of High-Frequency Seismic Effects (RP2722-23)	$214,900 19 months	Jack R. Benjamin & Associates Inc. / *R. Kassawara*
Guidelines for Product Performance Based Audits of Suppliers (RPQ101-19)	$127,000 10 months	Science Applications International Corp. / *W. Blanin*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303, (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Reports will be provided to nonmember U.S. utilities only upon purchase of a license, the price for which will be equal to the price of EPRI membership. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of EPRI reports on request. To order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

CUSTOMER SYSTEMS

1987 Survey of Commercial-Sector Demand-Side Management Programs
CU-6294 Final Report (RP2884-1), $100
Contractor: Battelle, Columbus Division
EPRI Project Managers: P. Hanser, W. Smith

Evaluation of Microcomputer Programs for Commercial Building Energy Analysis
CU-6457 Final Report (RP2891-2), $100
Contractor: Arthur D. Little Inc.
EPRI Project Manager: M. Blatt

Soil and Rock Classification According to Thermal Conductivity: Design of Ground-Coupled Heat Pump Systems
CU-6482 Final Report (RP2892-3), $47.50
Contractor: STS Consultants Ltd.
EPRI Project Manager: P. Joyner

Residential End-Use Energy Consumption: A Survey of Conditional Demand Estimates
CU-6487 Final Report (RP2547-1), $100
Contractors: Cambridge Systematics Inc.; Regional Economic Research Inc.
EPRI Project Manager: S. Braithwait

1988 Survey of Residential-Sector Demand-Side Management Programs
CU-6546 Final Report (RP2884-1), $100
Contractor: Battelle, Columbus Division
EPRI Project Manager: P. Hanser

Operation and Performance of Commercial Cool Storage Systems, Vols. 1 and 2
CU-6561 Special Report (RP2732-5), Vol. 1, $100; Vol. 2, $100
Contractor: Science Applications International Corp.
EPRI Project Managers: D. Geistert, R. Wendland

ELECTRICAL SYSTEMS

Substation Voltage Upgrading
EL-6474 Final Report (RP2794-1), $10,000
Contractor: General Electric Co.
EPRI Project Manager: J. Porter

Knowledge-Based System: Voltage and VAR Dispatch
EL-6483 Final Report (RP2944-2), $25
Contractor: Union Electric Co.
EPRI Project Manager: D. Curtice

Proceedings: Power System Planning and Engineering—Research Needs and Priorities
EL-6503 Proceedings (RP2473-34), $25
Contractor: Southern Company Services Inc.
EPRI Project Manager: M. Lauby

Pilot Study of Residential Power Frequency Magnetic Fields
EL-6509 Final Report (RP2942), $40
Contractor: General Electric Co.
EPRI Project Managers: J. Mitsche, G. Rauch

ENVIRONMENT

EMDEX System Manuals, Vols. 1 and 2
EN-6518 Interim Report (RP799-16), Vol. 1, $25; Vol. 2, $32.50
Contractor: Enertech Consultants
EPRI Project Manager: S. Sussman

Paleoecological Investigation of Recent Lake Acidification (PIRLA): 1983–1985
EN-6526 Interim Report (RP2174-10), $40
Contractor: Indiana University Foundation
EPRI Project Manager: R. Goldstein

EXPLORATORY RESEARCH

Fiber-Optic Sensing Workshop
ER-6537 Proceedings (RP8000-34), $25
Contractor: Foster-Miller Inc.
EPRI Project Manager: J. Weiss

GENERATION AND STORAGE

Reducing Power Plant Emissions by Controlling Coal Quality
GS-6281 Proceedings (RP1400), $500
Contractor: Writing Consultants Associated
EPRI Project Managers: C. Harrison, J. Hervol

Operating Problems With Startup Valves in U.S. and Japanese Supercritical Steam Generators
GS-6397 Topical Report (RP1403-19), $32.50
Contractors: Foster Wheeler Energy Corp.; Ishikawajima-Harima Heavy Industries Co., Ltd.; Bailey Japan Co., Ltd.
EPRI Project Manager: W. Bakker

Planar Solid Oxide Fuel Cell Development
GS-6504 Final Report (RP1676-9), $25
Contractor: Ztek Corp.
EPRI Project Manager: R. Goldstein

Solid Particle Erosion of Steam Turbine Components: 1989 Workshop
GS-6535 Proceedings (RP1885-6), $47.50
Contractor: Encor-America Inc.
EPRI Project Manager: V. Hulina

Microbial Conversion of Coal
GS-6553 Final Report (RP8003-5), $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Managers: S. Yunker, L. Atherton

Hydrogen Conference
GS-6563 Proceedings (RP1086-22), $40
Contractor: Technology Transition Corp.
EPRI Project Manager: B. Mehta

Nontoxic Foul-Release Coatings
GS-6565 Final Report (RP1689-9), $500
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: J. Tsou

Targeted Chlorination Schedules
GS-6576 Final Report (RP2300-2), $47.50
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: W. Chow

NUCLEAR POWER

ARMP-02 Documentation Part II, Chapter 5—EPRI-PRESS Computer Code Manuals, Vol. 1: Theory and Numerics
NP-4574-CCM Computer Code Manual (RP1252-6), $40
Contractor: S. Levy Inc.
EPRI Project Managers: W. Eich, R. Breen

Below Regulatory Concern Owners Group: BRC Waste Variability Evaluation
NP-5685 Final Report (RP101-10, -16), $1000
Contractors: Vance & Associates; National Nuclear
EPRI Project Manager: P. Robinson

Valve Motor Operator Improvements
NP-5686 Final Report (RP2233-2), $40
Contractor: Foster-Miller Inc.
EPRI Project Manager: B. Brooks

In-Plant Measurement of Corrosive Ions in Water
NP-6308 Final Report (RP1447-1), $32.50
Contractor: General Electric Co.
EPRI Project Manager: T. Passell

Avoiding Steam-Bubble-Collapse-Induced Water Hammers in Piping Systems
NP-6447 Interim Report (RP2856-2), $32.50
Contractor: Massachusetts Institute of Technology
EPRI Project Managers: J. Kim, M. Merilo

Lower-Bound Magnitude for Probabilistic Seismic Hazard Assessment
NP-6496 Final Report (RP2556-25), $47.50
Contractor: Jack R. Benjamin and Associates Inc.
EPRI Project Manager: J. Stepp

The Effects of Soil-Structure Interaction on Laterally Excited Liquid-Storage Tanks
NP-6500 Interim Report (RP2907-2), $40
Contractor: Rice University
EPRI Project Manager: H. Tang

Functional Specifications for a Radioactive Waste Decision Support System
NP-6501 Final Report (RP2414-19), $1000
Contractor: Odetics Inc.
EPRI Project Managers: F. Gelhaus, P. Robinson

Steam Generator Model Validation and Advanced Feedwater Control System Design for the Maanshan PWR
NP-6506 Final Report (RP2126-7), $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: B. Sun

Application of Modern Computer Technology to EPRI Nuclear Computer Programs
NP-6507 Final Report (RP2961-1), $32.50
Contractor: Power Computing Co.
EPRI Project Manager: J. Naser

In-Process Acoustic Emission Monitoring of Dissimilar Metal Welding
NP-6508-M Final Report (RP2928-2), $25
Contractor: Chamberlain Manufacturing Corp.
EPRI Project Manager: M. Behravesh

Corrosion-Product Release in LWRs
NP-6512 Final Report (RP2008-1), $32.50
Contractor: Atomic Energy of Canada Ltd.
EPRI Project Manager: H. Ocken

Reliability of the Southwest Research Institute TREES Rotor Bore Inspection System
NP-6513 Final Report (RP1570-2), $25
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: G. Dau

Robotics Program Development: Applicable Lessons Learned From TMI-2
NP-6521 Final Report (RP2558-2), $32.50
Contractor: Pentek Inc.
EPRI Project Manager: R. Lambert

Elimination of Soluble Boron for a New PWR Design
NP-6536 Final Report (RP2614-24), $32.50
Contractor: Combustion Engineering Inc.
EPRI Project Managers: W. Sugnet, J. Yedidia

Methodology Estimating Number of Failed Fuel Rods and Defect Size
NP-6554 Final Report (RP2229-1), $32.50
Contractor: Battelle Pacific Northwest Laboratories
EPRI Project Managers: P. Rudling, R. Yang

UTILITY PLANNING

Customer Demand for Service Reliability: A Synthesis of the Outage Costs Literature
P-6510 Final Report (RP2801-1), $32.50
Contractor: Laurits R. Christensen Associates Inc.
EPRI Project Manager: H. Chao

Why Issues Emerge
P-6552 Final Report (RP2345-55), $32.50
Contractor: J. F. Coates Inc.
EPRI Project Manager: S. Feher

New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. EPRI member utilities, in paying their membership fees, prepay all royalties. EPRI software is not available to nonmember U.S. utilities. No royalties are charged to nonutility public service organizations in the United States, including government agencies, universities, and other tax-exempt organizations. Industrial organizations are required to pay royalties. Basic support in installing the codes is available at no charge from EPSC; however, a consulting fee may be charged for extensive support.

For more information about EPSC and licensing arrangements, EPRI member utilities, government agencies, universities, and other tax-exempt organizations should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207, (214) 655-8883. Industrial organizations should contact EPRI's Manager of Licensing, PO Box 10412, Palo Alto, California 94303, (415) 855-2866.

APLUS: Analysis of Plant Utility Systems
Version 1.0 (IBM PC)
Contractor: Tensa Services Inc.
EPRI Project Manager: K. R. Amarnath

ASCON-I: Adjustable Speed Drive Analysis Technique
Version 3.1 (IBM PC)
Contractor: CRS Sirrine Inc.
EPRI Project Manager: Marek Samoty

BAPMAN: Technology Transfer and Benefits Assessment
Version 1.0 (IBM PC)
Contractor: ADROIT Software
EPRI Project Manager: Edward Beardsworth

COOLAID: Thermal Energy Storage/Demand-Side Planning/Load and Market Research
Version 2.1 (IBM PC)
Contractor: Regional Economic Research
EPRI Project Managers: Steven Braithwait, Ron Wendland

CQIM: Coal Quality Information Manager
Version 1.0 (IBM PC), GS-6393
Contractor: Black & Veatch Engineers-Architects
EPRI Project Manager: Arun Mehta

DIRECT: Transient Energy Function Program
Version 2.1 (IBM PC), EL-4980
Contractor: Ontario Hydro
EPRI Project Manager: James Mitsche

EAM: Ecosystem Assessment Model
Version 1.0 (IBM PC), EA-4907
Contractor: Tetra Tech Inc.
EPRI Project Manager: Donald Porcella

EMTPIN: Front-End Processor for EMTP
Version 2.0 (IBM PC, VAX)
Contractor: Power Computing Co.
EPRI Project Manager: Mark Lauby

FASTCHEM: Code for Predicting Groundwater Flow and Solute Migration
Version 1.0 (IBM PC), EA-5871
Contractor: Battelle Pacific Northwest Laboratories
EPRI Project Manager: Dave McIntosh

HPSCAN: Heat Pump Screening Analysis
Version 1.0 (IBM PC), CU-6445-CCML
Contractor: ICI-Tensa Services
EPRI Project Manager: K. R. Amarnath

IMIS: Industrial Market Information System
Version 1.0 (IBM PC)
Contractor: Battelle, Columbus Laboratories
EPRI Project Manager: Robert Jeffress

MULTEQ: Equilibrium of an Electrolytic Solution With Vapor-Liquid Partitioning and Precipitation
Version 8.0 (IBM PC), NP-5561-CCM
Contractor: S-Cubed
EPRI Project Manager: Peter Paine

PULSE: Relative Share Estimation for Residential DSM Programs
Version 1.0 (IBM PC), EM-6136-CCML
Contractor: National Analysis
EPRI Project Manager: Larry Lewis

SGA-ACDCFLT: AC/DC Fault Analysis
Version 1.0 (IBM)
Contractor: Georgia Institute of Technology
EPRI Project Manager: Gilbert Addis

SGA-DCGRND: DC Grounding System Model
Version 1.0 (IBM)
Contractor: Georgia Institute of Technology
EPRI Project Manager: Gilbert Addis

SGA-SGSYS: Substation Grounding Analysis
Version 4.1 (IBM, IBM PC)
Contractor: Georgia Institute of Technology
EPRI Project Manager: Gilbert Addis

SGWORKSTATION: System Grounding Workstation
Version 1.0 (IBM PC)
Contractor: Power Computing Co.
EPRI Project Manager: Gilbert Addis

SSSP: Small Signal Stability Program
Version 1.1 (IBM PC), EL-5798
Contractor: Power Computing Co.
EPRI Project Manager: Mark Lauby

WHSIM: Wellhead Binary-Cycle Simulator
Version 1.0 (IBM PC), GS-6302
Contractor: ESSCOR Inc.
EPRI Project Manager: Jonne Berning

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

MARCH

6–9
International Symposium: Performance Improvement, Retrofitting, and Repowering of Fossil Fuel Power Plants
Washington, D.C.
Contact: Gary Poe, (415) 855-8969

7–9
Industrial Applications of Plasma
Palo Alto, California
Contact: Mary Kakaio, (415) 855-2561

20–23
EPRI–EPA Symposium: Transfer and Utilization of Particulate Control Technology
San Diego, California
Contact: Ramsay Chang, (415) 855-2535

21–23
2d National Conference and Exhibition on Power Quality for End-Use Applications
Burlingame, California
Contact: Marek Samotyj, (415) 855-2980

26–29
Electric Vehicle Ride and Drive Demonstration
Anaheim, California
Contact: Jim Janasik, (415) 855-2486

27–28
Pulp and Paper Workshop
Atlanta, Georgia
Contact: Ammi Amarnath, (415) 855-2548

APRIL

2–6
Analysis and Design of Transmission Structures
Haslet, Texas
Contact: Dick Kennon, (415) 855-2311

10–11
Competitive Power Markets: Implications for Utility Operations and Strategic Positioning
Baltimore, Maryland
Contact: Steve Chapel, (415) 855-2608

17–19
Conference: Life Assessment and Repair Technology for Combustion Turbine Hot-Section Components
Phoenix, Arizona
Contact: Vis Viswanathan, (415) 855-2450, or James Allen, (415) 855-8929

17–20
Transmission Tower Foundations
Haslet, Texas
Contact: Dick Kennon, (415) 855-2311

23–25
New Technologies: Issues in Occupational and Environmental Health
Bethesda, Maryland
Contact: Cary Young, (408) 755-4301

24–27
Electrical Potpourri
Haslet, Texas
Contact: Dick Kennon, (415) 855-2311

MAY

1–3
1st International Symposium on Biological Processing of Coal
Orlando, Florida
Contact: Stanley Yunker, (415) 855-2815

8–11
1990 SO_2 Control Symposium
New Orleans, Louisiana
Contact: Paul Radcliffe, (415) 855-2720

JUNE

11–13
Applications of Power Production Simulation
Washington, D.C.
Contact: Mark Lauby, (415) 855-2304

JULY

29–August 3
International Conference: Indoor Air Quality and Climate
Toronto, Canada
Contact: Cary Young, (408) 755-4301

AUGUST

28–30
International Conference: Measuring Waterborne Trace Substances
Baltimore, Maryland
Contact: Winston Chow, (415) 855-2868

SEPTEMBER

18–20
Conference: Condenser Technology
Boston, Massachusetts
Contact: John Tsou, (415) 855-2220

Authors and Articles


Sagan


Sussman


Rafferty


Black


Kheifets


Rauch


Schneider


Sharma


Edmonds


White


Porcella


Goldstein

Pursuing the Science of EMF (page 4) was written by Taylor Moore, the *Journal*'s senior feature writer, with guidance from several staff members of EPRI's Environment and Electrical Systems divisions.

Leonard Sagan, manager of radiation studies, came to EPRI in 1978. Formerly a clinical director of environmental medicine, he also was once an AEC researcher in nuclear medicine.

Stanley Sussman, a physicist and subprogram manager for exposure assessment studies, rejoined EPRI in 1987 after five years in instrument development. Between 1978 and 1981 he managed research in systems modeling.

Charles Rafferty, a biophysicist and project manager for studies of EMF effects, joined EPRI in 1987. He was formerly with the Walter Reed Army Institute for Research, where he studied the biomedical effects of microwave radiation at subcellular levels.

Robert Black, an epidemiologist, has been a project manager for EMF studies since 1979. He came to EPRI from the University of Texas School of Public Health, where he earned an MPH.

Leeka Kheifets, also an epidemiologist, came to EPRI in 1988 after two years in occupational health surveillance and management at Syntex Corp. and three years as a biostatistician at Environmental Health Associates.

Greg Rauch, a project manager in the Electrical Systems Division, guides research in magnetic fields and power quality. He joined EPRI in 1988 after 11 years with General Electric. ■

Superconductivity: Dealing in Futures (page 18) was written by Jon Cohen, science writer, with information from managers in three EPRI research groups.

Tom Schneider is a senior science adviser in the Office of Exploratory Research, responsible for investigations in physics and the mathematical sciences. He has been with EPRI since 1977, following four years as a research physicist with Public Service Electric & Gas in New Jersey.

Dave Sharma is a subprogram manager in the Electrical Systems Division, guiding research in underground transmission and also working with an Institute-wide group on utility applications of high-temperature superconductivity. He came to EPRI in 1980 after 11 years with General Electric.

Jim Edmonds, a technical adviser in the Generation and Storage Division, has been with EPRI since 1978, working in the Electrical Systems Division until June 1988 and then on loan for a year to the National Science Foundation. He formerly was with American Electric Power Service.

J C. White has managed the Rotating Machinery Program since 1980. He came to EPRI in 1979 after 32 years in electrical machinery engineering with General Electric. ■

Working With the Watershed (page 28) was written by David Boutacoff, *Journal* feature writer, in cooperation with two staff members of EPRI's Environment Division.

Don Porcella, a project manager for ecological studies, joined EPRI in 1984, after six years with Tetra Tech. Still earlier, he was on the engineering faculty at Utah State for nine years.

Robert Goldstein, also in ecological studies, is the subprogram manager for systems ecology. He has been with EPRI since 1975, before which he was at Oak Ridge National Laboratory. ■

Index to 1989 EPRI Journal

Acid deposition, effects on forests O/N 14
Ac power sources at nuclear plants, reliability data on J/A 54
Adapa, Rambabu O/N 57
Adjustable-speed drives, for power plants Jun 34
Advisory Council, EPRI
  member profiles A/M 14, Sep 20
  seminar on technological innovation Mar 16
Aerosol behavior, in reactor containment buildings A/M 45
Affiliate Member Program of EPRI's Customer Systems Division O/N 1, 4
Air quality
  effects on forests O/N 14
  indoor-outdoor, and health J/F 42
  and ozone Jun 14, Sep 4
  trace gas measurement Jun 42
Alternative fuel, methanol as O/N 24
Amarnath, Ammi J/F 61, O/N 57
Atherton, Linda O/N 57
Atmospheric chemistry
  and ozone Jun 14, Sep 4
  trace gas measurement Jun 42
Automobiles, infrared paint curing for Sep 26

Balu, Neal Sep 56, O/N 57
Barker, Brent Mar 57
Batteries. *See* Energy storage
Birk, Jim J/A 1, 61
Blatt, Morton Dec 1, 61
Boiler tube failure
  expert system on A/M 24
  remedies for J/F 54
Boiling water reactors. *See* Nuclear power plants

CATALYST planning process O/N 46
CECIL robot Mar 30, A/M 42
Center for Materials Fabrication O/N 4
Center for Metals Production O/N 4
CFCs. *See* Chlorofluorocarbons.
Chlorofluorocarbons Jun 14, Sep 1, 4
Clean coal technologies J/F 1, 4. *See also* Fluidized-bed combustion, Low-NO_x burner
Coal analysis, laboratory guidelines for Sep 38
Coal ash use, assessing environmental effects of Dec 52
Coal-fired power plants. *See also* Coal quality
  advanced technologies for (overview) J/F 4
  boiler tube failures in J/F 54
  effects on fish O/N 49
  emissions control for J/F 4, Mar 42, A/M 40
  expert systems for A/M 24
  fluidized-bed demonstration Mar 26
  water management in O/N 52
Coal gasification, Shell process for Jun 38
Coal quality
  assessing impacts of Dec 49
  laboratory analysis of Sep 38
Coal Quality Impact Model Dec 49
Cogeneration, evaluating options for O/N 38
COGENMASTER code O/N 38
Cold-air-velocity technique, for reducing fly ash erosion J/F 54
Cold fusion A/M 20, J/A 42
Commercial sector. *See also* Refrigeration and cooling technologies
  advanced lighting for Dec 1, 4
  End-Use TAG for Jun 36
  foodservice equipment in Sep 43
Competition, international, and U.S. industry Mar 16, O/N 1, 4
Compressed-air energy storage J/F 30. *See also* Energy storage
Cool-Storage Supervisory Controller O/N 43
Cost management, implementation process for O/N 40
COQIM. *See* Coal Quality Impact Model
CRAFT expert system Mar 49. *See also* Expert systems
Cuttice, David A/M 56
Customer preferences, and value-based planning J/F 22

Dau, Gary Dec 61
Demand-side management/planning
  and cogeneration O/N 38
  and commercial lighting Dec 1, 4
  DSM program monitoring J/F 46
  End-Use TAG Jun 36
  and home automation Dec 24
  and industrial sector Mar 44; Sep 36
  and residential direct load control Dec 44
  in value-based planning J/F 22
DeMeo, Edgar Mar 1, 57
DeVine, Jack A/M 1, 56
Diagnostics
  expert systems for A/M 24
  for gas turbines Dec 56
  for power system control Mar 49
  for substation equipment Sep 40
Dielectric heating and drying J/A 44
Direct load control, residential, measuring impacts of Dec 44
Divakaruni, Murthy A/M 56

Earthquakes, data on power system performance in Jun 22
Editorials
  CFCs and the Energy-Environment Puzzle Sep 1
  Cooperative Development of Clean Coal Technology J/F 1
  FACTS and the Future Jun 1
  Getting Down to Business With Thin Films Mar 1
  Lighting for Efficiency and Productivity Dec 1
  The New Industrial Imperative O/N 1
  The Promise of Passive Plants A/M 1
  Storage: The Competitive Edge J/A 1
Electric vehicles J/F 52
Electrification
  historical role in U.S. manufacturing Dec 16
  and international competition Mar 16; O/N 1, 4
Electromagnetic Transients Program A/M 38, O/N 32
Electrostatic precipitators Mar 42
Electrotechnologies
  for commercial foodservice Sep 43
  dielectric heating J/A 44

Electrotechnologies (*cont.*)
freeze concentration J/F 16
guide for assessing Jun 36
industrial, EPRI program on O/N 1, 4
industrial market for Sep 36, O/N 4
and industrial productivity Mar 16; O/N 1, 4; Dec 16
infrared paint curing Sep 26
refrigeration and cooling, and CFCs Sep 1, 4
Emissions control
of nitrogen oxides J/F 4, A/M 40
of particulates Mar 42
of sulfur dioxide J/F 4
EMTP code A/M 38, O/N 32
End-Use Technical Assessment Guide Jun 36
End-use technologies. *See* Electric vehicles; Electrotechnologies; Home automation; Lighting systems.
Energy efficiency
and adjustable-speed drives Jun 34
and advanced lighting systems Dec 1, 4
and cool-storage systems O/N 43
and dielectric heating J/A 44
and electrification Mar 16, O/N 4; Dec 16
and foodservice equipment Sep 43
and freeze concentration J/F 16
and infrared paint curing Sep 26
and refrigeration and cooling, and CFCs Sep 1, 4
Energy storage, strategies and technologies for J/A 1, 4. *See also* Compressed-air energy storage
Environmental effects
of coal ash use Dec 52
of manufactured gas plant wastes J/A 22
of power plants on fish O/N 49
related to ozone Jun 14; Sep 1, 4
of stresses on forests O/N 14
EPRI
Advisory Council Mar 16, A/M 14, Sep 20
Affiliate Member Program (Customer Systems Division) O/N 1, 4
Expert systems A/M 24. *See also* CRAFT
Exploratory research
on cold fusion A/M 20; J/A 42
on methanol synthesis O/N 24

FACTS (flexible ac transmission system) Jun 1, 4
FASTCHEM code A/M 47
FEATURE code J/F 49
Features
CFCs: The Challenge of Doing Without Sep 4
Concern Over Ozone Jun 14
Dean Wilson: Welcoming the Opportunities of Change A/M 14
Delivering On-Line Expertise A/M 24
Diagnosing Forest Stress O/N 14
Electrification: Key to Manufacturing Productivity Dec 16
Emerging Strategies for Energy Storage J/A 4
EMTP: Designing for Disaster O/N 32
Fluidized Bed Fires Up at TVA Mar 26
Freeze Concentration: An Energy-Efficient Separation Process J/F 16
The Future of Transmission: Switching to Silicon Jun 4
In Hot Pursuit of Cold Fusion A/M 20
Features (*cont.*)
Innovation and Industrial Development Mar 16
Integrated Home Automation Dec 24
Is Cost the Only Measure of Electricity Value? J/F 22
Lighting the Commercial World Dec 4
Managing the Gaslight Legacy J/A 22
Methanol: A Fuel for the Future? O/N 24
The NDE Center: Celebrating a Decade of Achievement Dec 32
New Interest in Passive Reactor Designs A/M 4
Pioneering CAES for Energy Storage J/F 30
Quickening the Pace in Clean Coal Technology J/F 4
Real-World Lessons in Seismic Safety Jun 22
The Return of American Industry O/N 4
Shining Promise for Infrared Paint Curing Sep 26
Sludgebuster for Steam Generators Mar 30
A Storm From the Sun J/A 14
Taking the Measure of Transmission Flows Sep 14
Thin Films: Expanding the Solar Marketplace Mar 4
TLWorkstation: Expert Assistance in Line Design J/A 32
Victoria Tschinkel: Enthusiasm for the Environment Sep 20
Fickett, Arnold Sep 1
Fish, power plant effects on O/N 49
Flue gas desulfurization J/F 4
Fluidized-bed combustion, TVA demonstration of Mar 26. *See also* Clean coal technologies
Fly ash erosion, of boiler tubes J/F 54
Foodservice equipment Sep 43
Forests, studies of stresses on O/N 14
Freeze concentration J/F 16
Frequency-modulated spectroscopy, for measuring trace gases Jun 42
Fuel cells Sep 34
Fuel upgrading J/F 4
Fusion, cold A/M 20; J/A 42

Gas-cooled reactor, modular high-temperature A/M 1, 4
Gasification–combined cycles, integrated
as clean coal technology J/F 4
and methanol production O/N 24
Shell coal gasification process Jun 38
Gas lighting, managing wastes associated with J/A 22
Gas turbine combustion viewing system Dec 56
Generation, advanced options for
fluidized-bed combustion J/F 4; Mar 26
fuel cells Sep 34
IGCC J/F 4; Jun 35
passive nuclear reactors A/M 1, 4
solar Mar 1, 4, 46
wind J/A 49
Geomagnetically induced currents J/A 14
Goldstein, Robert O/N 57
Groundwater protection
and coal ash use sites Dec 52
FASTCHEM code A/M 47
Groundwater protection (*cont.*)
and manufactured gas plant wastes J/A 22
and underground storage tanks A/M 36

Hakkannen, Chuck Jun 48
Hanser, Philip J/F 61
Harry I, Leslie O/N 1, 57
Health effects
of air pollution, community studies of J/F 42
of manufactured gas plant wastes J/A 22
of ozone Jun 14
of toxic chemicals, assessing Dec 42
Hingorani, Narain Jun 1; J/A 61
Home automation Dec 24
Hydropower plants, effects on fish O/N 49

IGCC. *See* Gasification–combined cycles, integrated
IMIS. *See* Industrial Market Information System
Industrial electrotechnologies. *See* Electrotechnologies
Industrial Market Information System Sep 36; O/N 4
Industrial productivity and technological innovation Mar 16; O/N 1, 4; Dec 16
Infrared paint curing Sep 26
Inspection technologies, evaluation of Dec 32
International competition, and U.S. industry Mar 16; O/N 1, 4
Iveson, Bob Jun 48; J/A 61; Sep 56

Jeffress, Bob Sep 56; O/N 57
Johnson, Karl Dec 61
Joyner, Powell Sep 56

Kassawara, Bob Jun 48
Kennon, Richard J/A 61
Kulik, Conrad O/N 56

Lang, James Dec 61
Lannus, Arvo Dec 61
Lauby, Mark O/N 57
Lighting systems, advanced, for the commercial sector Dec 1, 4
Light water reactors, advanced passive A/M 1, 4. *See also* Nuclear power plants
Liquid metal reactor A/M 1, 4
Load control, residential Dec 44
Load management. *See* Demand-side management/planning
Loop flows Sep 14. *See also* FACTS
Low-NO_x burner A/M 40. *See also* Clean coal technologies
Low-rank coals
analyzing Sep 38
upgrading J/F 4

Manufactured gas plants, site management J/A 22
Manufacturing productivity. *See* Industrial productivity
Mehta, Ben J/F 61

Methanol O/N 24
Mueller, Peter Jun 48

Nilsson, Stig J/A 61
Nitrogen oxides
control of J/F 1, 4, A/M 40
and ozone Jun 14
Nondestructive evaluation, of turbine disks J/F 44
Nondestructive Evaluation Center Dec 32
NO_x *See* Nitrogen oxides
Nuclear fusion, cold A/M 20, J/A 42
Nuclear power plants. *See also* Steam generators
advanced reactor designs A/M 1, 4
expert systems for A/M 24
inspection technologies for J/F 44, Dec 32
radiation control in Sep 46
reactor safety studies A/M 45
seismic safety of Jun 22
station blackouts at J/A 54

Operator training simulator, for power system control center personnel Mar 49
Ozone
as air pollutant Jun 14, O/N 14
depletion of, and CFCs Jun 14, Sep 1, 4

Particulates, control of Mar 42
Passive safety features, in advanced reactor designs A/M 1, 4
Peterson, Terry Mar 57
Photovoltaics
high-concentration Mar 46
thin-film Mar 1, 4
Planning. *See* Demand-side management/planning, Utility planning
Pollak, Robert J/F 61
Power electronics
adjustable-speed drives Jun 34
center for J/A 46
and end-use power quality Mar 40, J/A 46
and home automation Dec 24
for transmission system control Jun 4
Power Electronics Applications Center J/A 46
Power flows, on-line calculation of Sep 14
Power plant effects on fish O/N 49
Power plant water management O/N 52
Power quality, end-use Mar 40, J/A 46
Power system analysis
expert systems for Mar 49, A/M 24
reliability evaluation J/A 52
stability analysis A/M 49
transient analysis with EMTP A/M 38, O/N 32
Power transfers, on-line tracking of Sep 14
See also Energy storage, FACTS
Pressurized water reactors. *See* Nuclear power plants, Steam generators
Preston, George J/F 61
Process Industries Coordination Office O/N 4
Pumped hydro. *See* Energy storage

QuickTANKS code A/M 36

Rabl, Veronika Dec 61
Radiation control technology Sep 46
Refrigeration and cooling technologies, and CFCs Sep 1, 4
Reliability data, on nuclear plant ac power sources J/A 54
Reliability evaluation, power system J/A 52
Renewable resources
photovoltaics Mar 1, 4, 46
wind power systems J/A 49
Residential sector. *See also* Refrigeration and cooling technologies
direct load control in Dec 44
End-Use TAG for Jun 36
home automation Dec 24
Retrofit technologies, for coal-fired plants
clean coal technologies (overview) J/F 4
for electrostatic precipitators Mar 42
low NO_x burner A/M 40
Risk assessment/management
for manufactured gas plant sites J/A 22
for underground storage tanks A/M 36
for utility chemicals Dec 42
Robot, for steam generator cleaning Mar 30, A/M 42
Rotating equipment, rotordynamic analysis of J/F 49

Santucci, Joseph A/M 56
Schalnker, Robert J/F 61, J/A 61
Schneider, Tom A/M 56
Schurr, Sam Dec 61
Seismic qualification, of nuclear plant equipment Jun 22
SEQUIL code O/N 52
Shell coal gasification process Jun 38
Smart House Dec 24
Smith, William J/F 61
Solar magnetic disturbances J/A 14
Solar power, photovoltaic Mar 1, 4, 46
Solvent wastes, management of Sep 48
Stability analysis, power system A/M 49
Stahlkopf, Karl A/M 56
Station blackouts, nuclear J/A 54
Steam generators, PWR
simulation tests Jun 32
sludge buildup and removal Mar 30, A/M 42
Storage tanks, underground A/M 36
Strategic cost management, implementation process for O/N 40
Stress corrosion cracking J/F 44, Dec 32
Substation equipment diagnostics Sep 40
Sulfur dioxide, control of J/F 4
Sun, Bill A/M 56
Superconducting magnetic energy storage. *See* Energy storage

TAG *See* Technical Assessment Guide
Technical Assessment Guide, End-Use Jun 36
Technological innovation
historical role in U.S. manufacturing Dec 16
and international competition Mar 16, O/N 1, 4
managing Mar 16
TEVan J/F 52
Thin-film photovoltaics Mar 1, 4
Thyristors Jun 4
TLWorkstation J/A 32
Torrens, Ian J/F 1, 61
TOXRISK code Dec 42
Trace gases, measurement of Jun 42
Training simulator, for power system operators Mar 49
Transformers, diagnostics for Sep 40
Transmission systems
advanced Jun 1, 4
line design J/A 32
measuring use of Sep 14
reliability evaluation for J/A 52
substation equipment diagnostics Sep 40
Tschinkel, Victoria (profile) Sep 20
Turbine disks, nondestructive evaluation of J/F 44

Ultrasonic testing J/F 44, Dec 32
Underground storage tanks A/M 36
Utility planning. *See also* Demand-side management/planning.
CATALYST process for O/N 46
methods for, under uncertainty O/N 46, Dec 47
and strategic cost management O/N 40
value-based J/F 22

Value-based planning, integrated J/F 22
Volatile organic compounds
from automobile paint Sep 26
and ozone Jun 14

Wall, Ian Jun 48
Waste management
coal ash use Dec 52
at manufactured gas plant sites J/A 22
modeling waste migration A/M 47
of spent solvents Sep 48
Water management, power plant O/N 52
WATERMAN code O/N 52
Williams, C. Lamar Mar 57
Wilson, Dean (profile) A/M 14
Wind power systems J/A 49
Wolk, Ron J/F 61
Worledge, David A/M 56

Yeager, Kurt J/F 61
Young, Frank Jun 48

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

NONPROFIT ORGANIZATION
U.S. POSTAGE
PAID
PERMIT NUMBER 99
REDWOOD CITY, CALIFORNIA

ADDRESS CORRECTION REQUESTED

EPRI JOURNAL

January/February 1990