Magnetic Field Research

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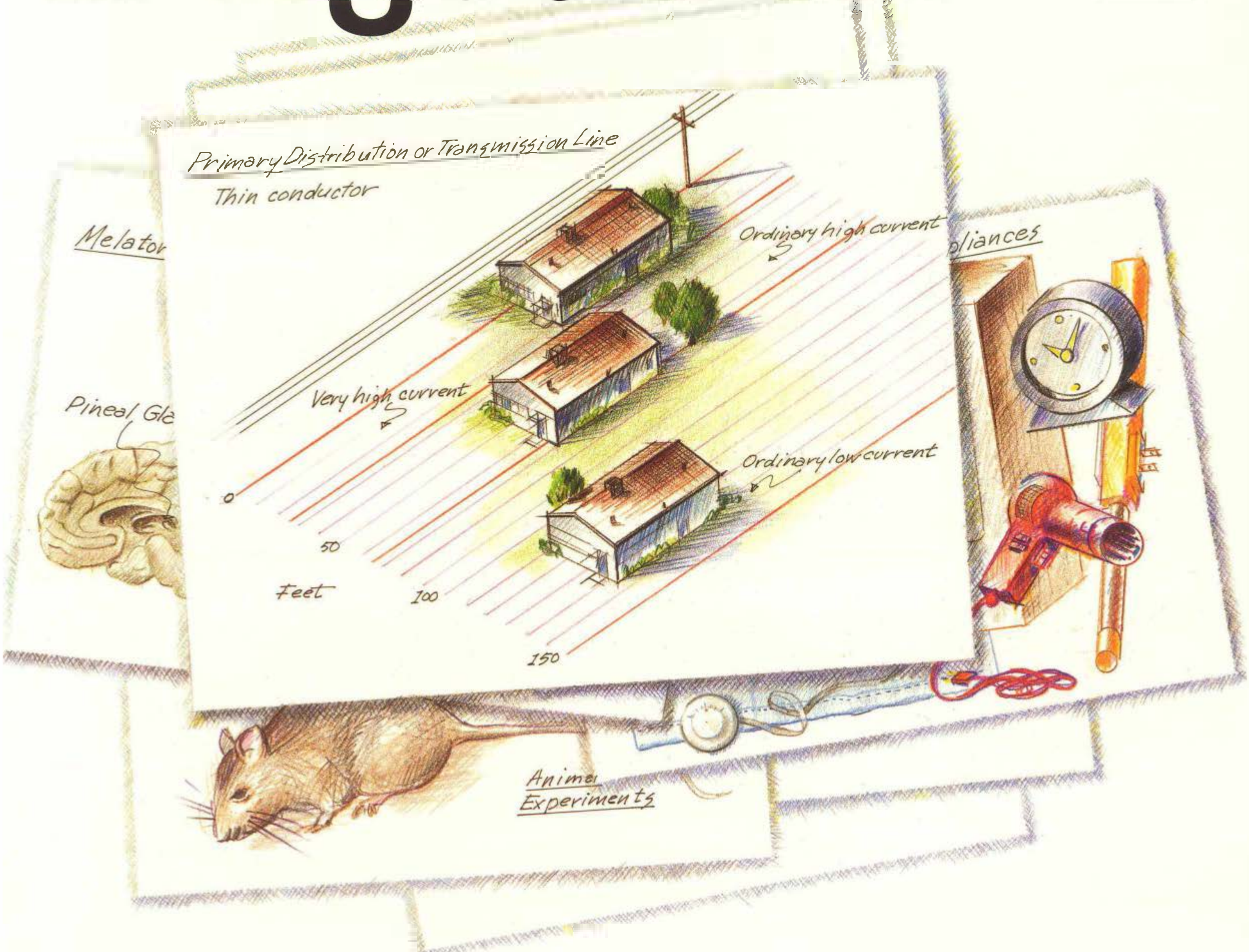

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Cover: Recent studies have sharpened interest in several key areas of EMF research, including the use of wiring configuration codes as surrogates for exposure measurements and the possibility that fields could suppress production of the hormone melatonin in humans.

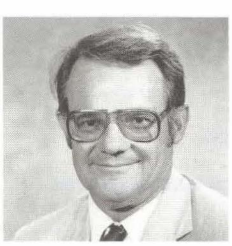
The Pace Quickens in EMF Research

The past year has been a very active one for EMF studies. The first results from a childhood leukemia study conducted by the University of Southern California were published in 1991. Other important epidemiological studies, including a major study of utility workers, are nearing completion. In the area of basic science, a number of animal studies, carefully planned over several years, are now under way. And pioneering exposure assessment work, especially in instrumentation development, has greatly advanced our ability to measure and understand human exposure.

Additional findings from ongoing studies will be released over the next several years. But at the same time, we will be devoting new funding and an increasing share of our R&D budget to a number of themes that have emerged from recent research and appear central to our understanding of field exposure and effects. These themes, which are discussed in this month's cover story, include the characterization of wiring configuration codes as markers of residential exposure and the effect of fields on the production of the hormone melatonin.

As the EMF issue grows, other research groups at EPRI are examining the issue from their perspectives. The Electrical Systems and Customer Systems divisions are characterizing sources of magnetic fields and will be developing strategies for field management. The Integrated Energy Systems Division has initiated a long-range project to develop an integrating decision framework for EMF-related issues. Recognizing the ongoing need to coordinate the Institute's work internally and to maintain liaison with outside activities, EPRI senior management has appointed Stan Sussman as EPRI's EMF issue manager. Stan will serve in this position as well as in his role as program manager for EMF health studies within the Environment Division.

The past year has also seen an increasing effort to expand and better coordinate federally funded EMF research, with the EPA, DOE, and NIOSH all engaged in setting research agendas. Congressional hearings on a number of recently introduced legislative initiatives to increase federal research spending are likely to take place this year. But even under the most favorable circumstances, results from new research initiatives would not be available until three to five years from now. Meanwhile the EPRI-funded program, infused with new resources geared to address specific issues, will remain a leading effort for years to come.



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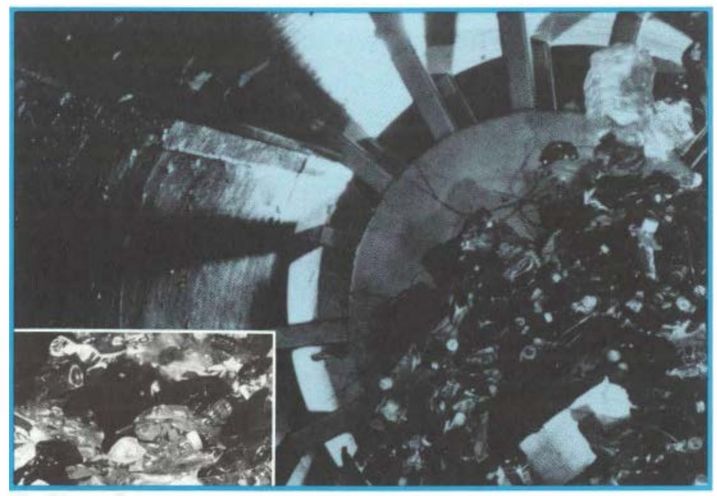
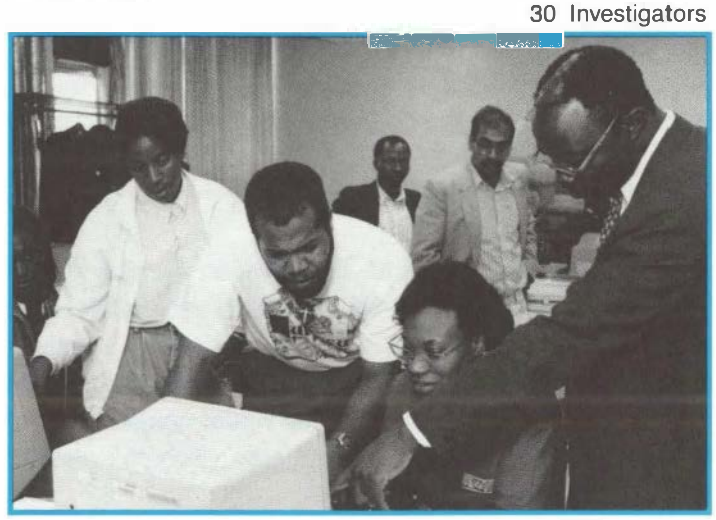
RESEARCH UPDATE





DEPARTMENTS

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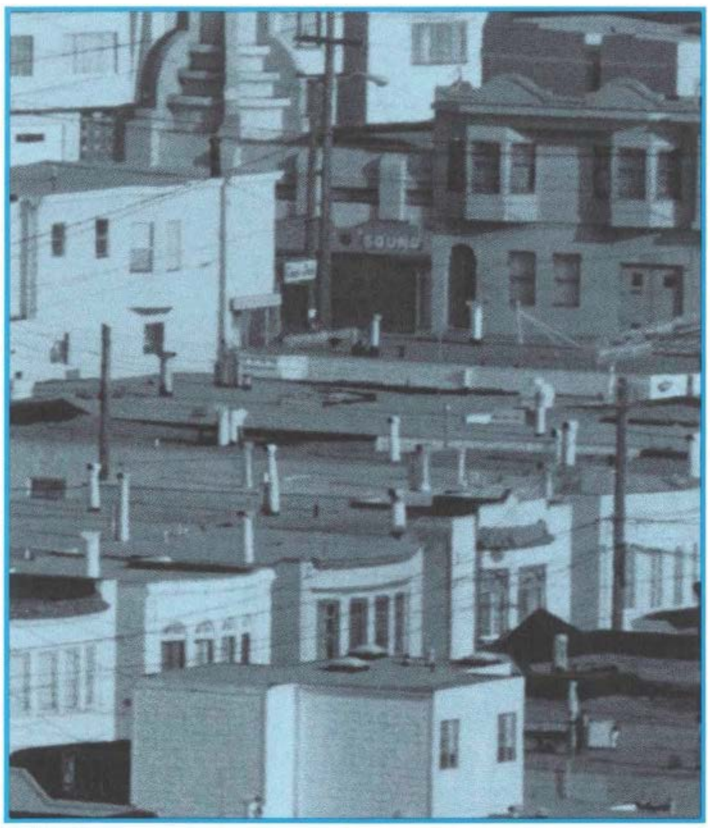

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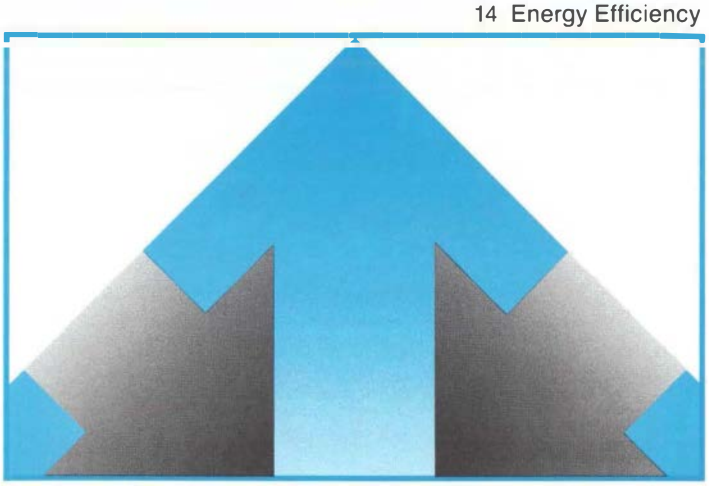
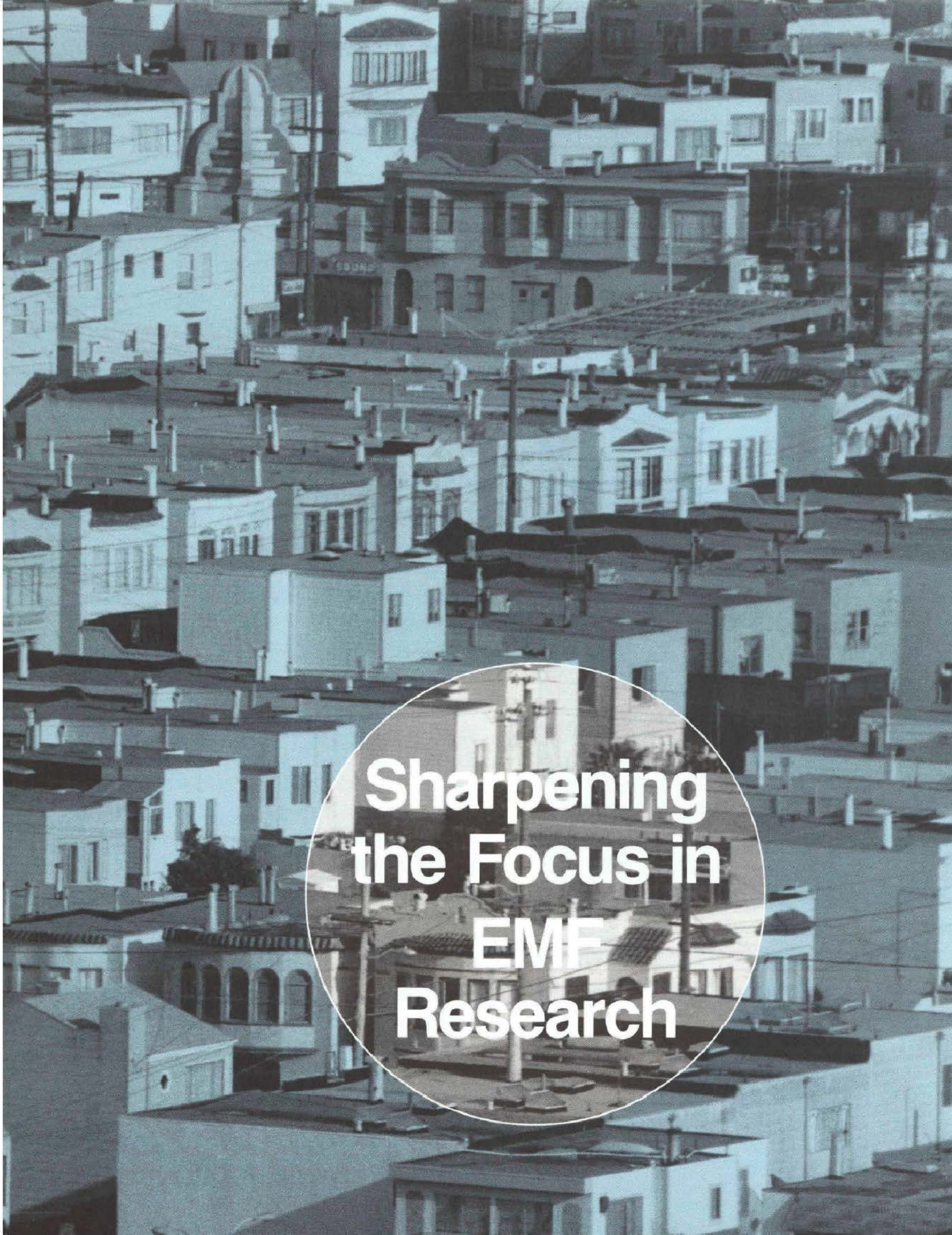
14 Energy Efficiency



Sharpening the Focus in EMF Research



EPRI'S RESEARCH INTO THE POSSIBLE HEALTH EFFECTS of exposure to electric and magnetic fields (EMF) is expanding and shifting into higher gear, in part in response to recent results from several key studies. Insights and priorities are evolving as researchers ponder the latest findings from both epidemiological studies and laboratory animal experiments.

Scientists involved in the research are far from ready to draw conclusions about whether EMF exposure could play a role in causing cancer. But increasing attention is now being given to a few key issues. These include suggestions, from the most comprehensive epidemiological investigation to date, of a possible relationship between magnetic fields and childhood leukemia. Researchers are now planning to probe more deeply the finding that wire codes—an indirect, surrogate measure of magnetic field exposure—are associated with an increased disease risk, as several studies have suggested.

Recent experiments with rats, meanwhile, have suggested that the suppression of melatonin may be a possible mechanism for a link between EMF and cancer. This hormone may aid in the body's suppression of the development of cancer. EPRI plans to sponsor, early this year, the first laboratory studies to investigate whether magnetic fields suppress melatonin synthesis in humans.

Some results are leading researchers to suspect that if there is a link between cancer and magnetic fields, it may be limited to some aspect of exposure that is more difficult to measure than the average field level, the factor typically measured in most studies to date. Exposure to intermittent or transient magnetic fields is a current focus of such attention. Recent research has spurred interest in learning more about the complex fields (including transients) that can be generated by such sources as common appliances. Yet the uncertainty and lack of agreement about what actually constitutes an exposure dose continue to plague EMF studies.

THE STORY IN BRIEF

Research results have yet to settle whether or not exposure to magnetic fields can adversely affect human health, but recent studies have provided strong pointers to several fertile areas of inquiry. EPRI is planning new studies that will dig deeper into the mysteries of these key focus areas, including questions about what wire code classifications really represent as indicators of residential magnetic field exposure and whether they are appropriate surrogates for actual exposure measurements. Other questions surround the hypothesis that magnetic fields could suppress production of the hormone melatonin, representing a possible mechanism of biological interaction. In addition to health studies, EPRI is continuing work in other parts of its comprehensive EMF research program, which includes identification of significant field sources and investigation of potential field management methods.

Another area at the forefront of a more focused EPRI health studies research agenda concerns exposure to magnetic fields in the occupational environment. Major ongoing studies of electrical workers in several large utilities in the United States, Canada, and France are expected to help clarify whether workers who are occupationally exposed to higher magnetic field levels have an increased risk of mortality from leukemia or brain cancer. This has been suggested by some studies that used job titles to assess exposures; actual on-the-job measurements should help provide a clearer answer. In addition, more-detailed studies of the complex occupational exposure environment are planned.

At the same time that EPRI's EMF health effects research is accelerating, momentum is gathering on the national and international levels for expanded government- and other industry-sponsored health effects research, which the Institute has urged for some time. Congressional efforts to better coordinate federally sponsored EMF health effects research recently led to the Department of Energy's designation as the lead agency. In addition to DOE, the Environmental Protection Agency, the National Cancer Institute, the National Institute of Environmental Health Sciences, the National Institute of Occupational Safety and Health, and the Food and Drug Administration are currently conducting or planning studies related to the health impacts of EMF exposure.

On another front, involving some public power and state regulatory authorities, organizing efforts are under way for a proposed cooperative national EMF research program including government agencies and the private sector. International support and involvement in EMF health research is likewise widening, say EPRI research managers. The number of countries sponsoring research has about doubled, to 25, and estimated annual spending has nearly doubled, to about $25 million worldwide, in just a few years.

Funding support for EPRI's EMF Health Studies Program, part of its Environment

Division, is increasing substantially, climbing from around $5.5 million last year to about $8.9 million in contract research this year. The increase "is largely for new work on questions about wire codes as markers for residential magnetic field exposures, and for an accelerated effort on melatonin," says Stanley Sussman, program manager for EMF health studies. "We also expect to do some related biological studies and develop new instrumentation for more measurement-based studies, including getting a better handle on transients."

A persistent epidemiological association

There is new interest in transients as possibly the special aspect or condition of magnetic field exposure that may be biologically effective, but transients remain poorly defined and understood technically and have not been adequately measured in any EMF study to date. The term has been used to refer to a number of different phenomena—to slowly varying or intermittent fields, for example, as well as to strong fields with millisecond-scale changes in intensity, including higher-frequency components.

The new interest in transients results partly from the failure of epidemiological studies to find a significant association between measured average magnetic fields and cancer. A handful of epidemiological studies have prompted much of the present concern over transients; researchers note that the apparent association in these studies is between cancer and surrogate measures of exposure that were originally developed to represent time-weighted average fields. Such indirect measures, which characterize residential human exposures to magnetic fields according to the proximity, number, and size of power lines near homes, are known as wire codes.

The finding of an apparent association between the incidence of leukemia in children and these wire codes, but not with directly measured fields, was perhaps the most puzzling finding in a major case-control epidemiological study conducted for EPRI. The study was conducted in Los Angeles at the University of Southern California School of Medicine by a team of researchers led by Dr. John Peters of the Department of Preventive Medicine. Results were widely reported last year.

The study of 232 cases of childhood leukemia seemed to confirm the results of two studies in the Denver area, the first of which originally developed the wire code classification method used by all three. The USC team found that children with leukemia were about twice as likely to live in homes with high-current wiring configurations as were children who did not have leukemia; the apparent doubling of risk was statistically significant. (Childhood leukemia is a rare disease, with an overall annual incidence of about 1 in 20,000 in the general population.)

But no clear association was seen when the USC researchers used actual indoor measurements of magnetic fields to characterize exposure. While a slight increase in risk was observed for the highest exposure category based on field measurements, the risk was not statistically significant and no dose-response relationship was demonstrated.

The USC investigators, however, did report statistically significant increases in leukemia risk among children whose parents recalled the youngsters' frequent use of two common household appliances—electric hair dryers and black-and-white television sets. Elevated, but not statistically significant, risk ratios were observed for the reported use of nine other appliances. Many appliances can produce strong magnetic fields, although levels decline rapidly with distance. The USC researchers noted that the findings on appliances may have been influenced by recall bias—specifically, the overreporting of their use by the parents of sick children.

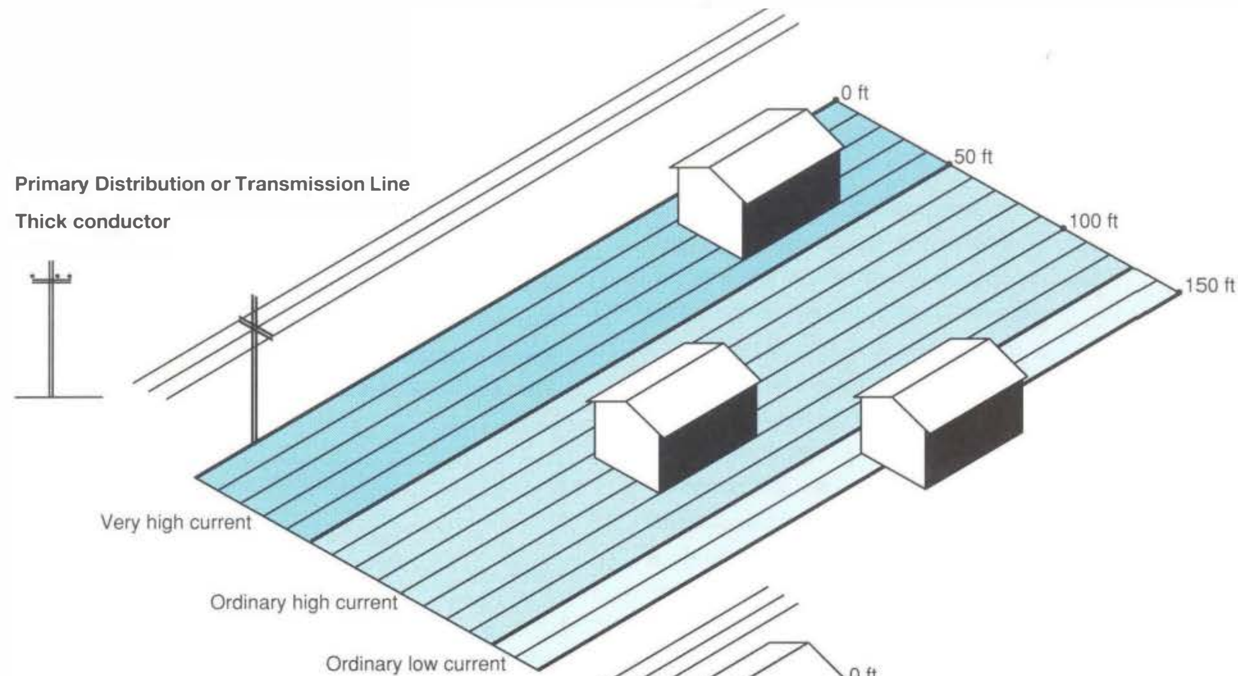
In an EPRI report on their work, the USC researchers concluded that their data offer "little support for the relationship between measured magnetic field exposure and leukemia risk, considerable support for a relationship between wiring configuration and leukemia risk, and considerable support for a relationship between children's electrical appliance use and leukemia risk."

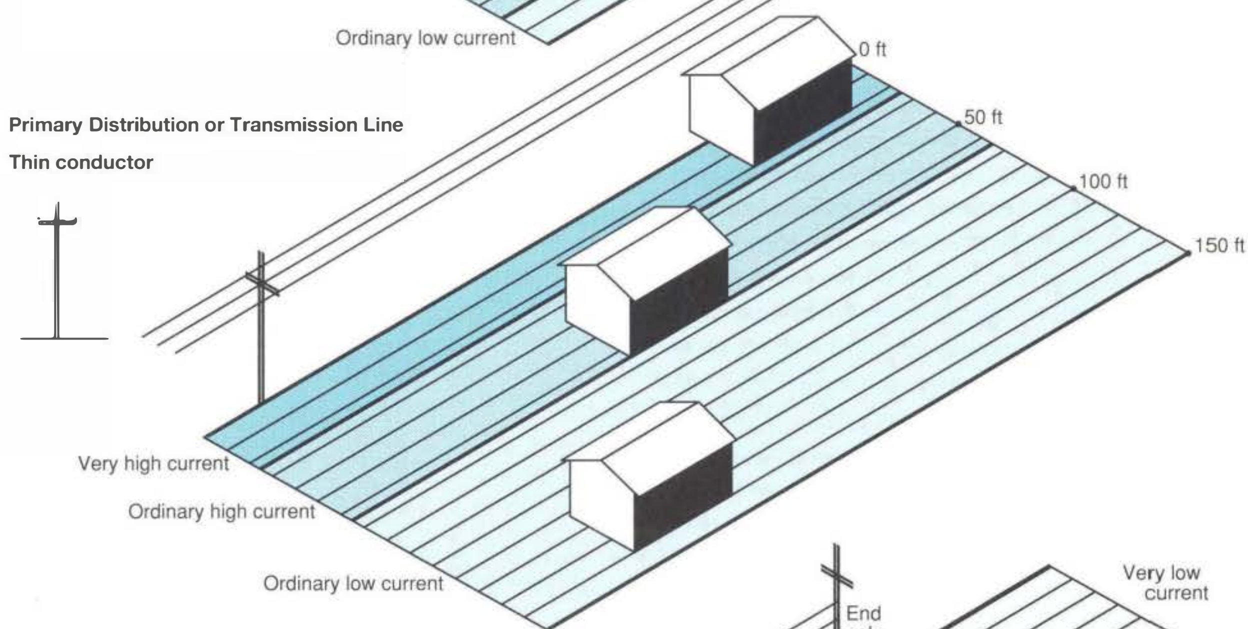
At a news conference last November, Dr. Stephanie London, a member of the USC team, explained that "if the association with wiring configuration is real, we are talking about a relatively weak effect, about a doubling in the risk of a rare cancer. With a weak association and an exposure that is difficult to measure, as we have here, a number of high-quality studies will be needed before we feel confident to conclude that electric and magnetic fields do or do not cause childhood leukemia."

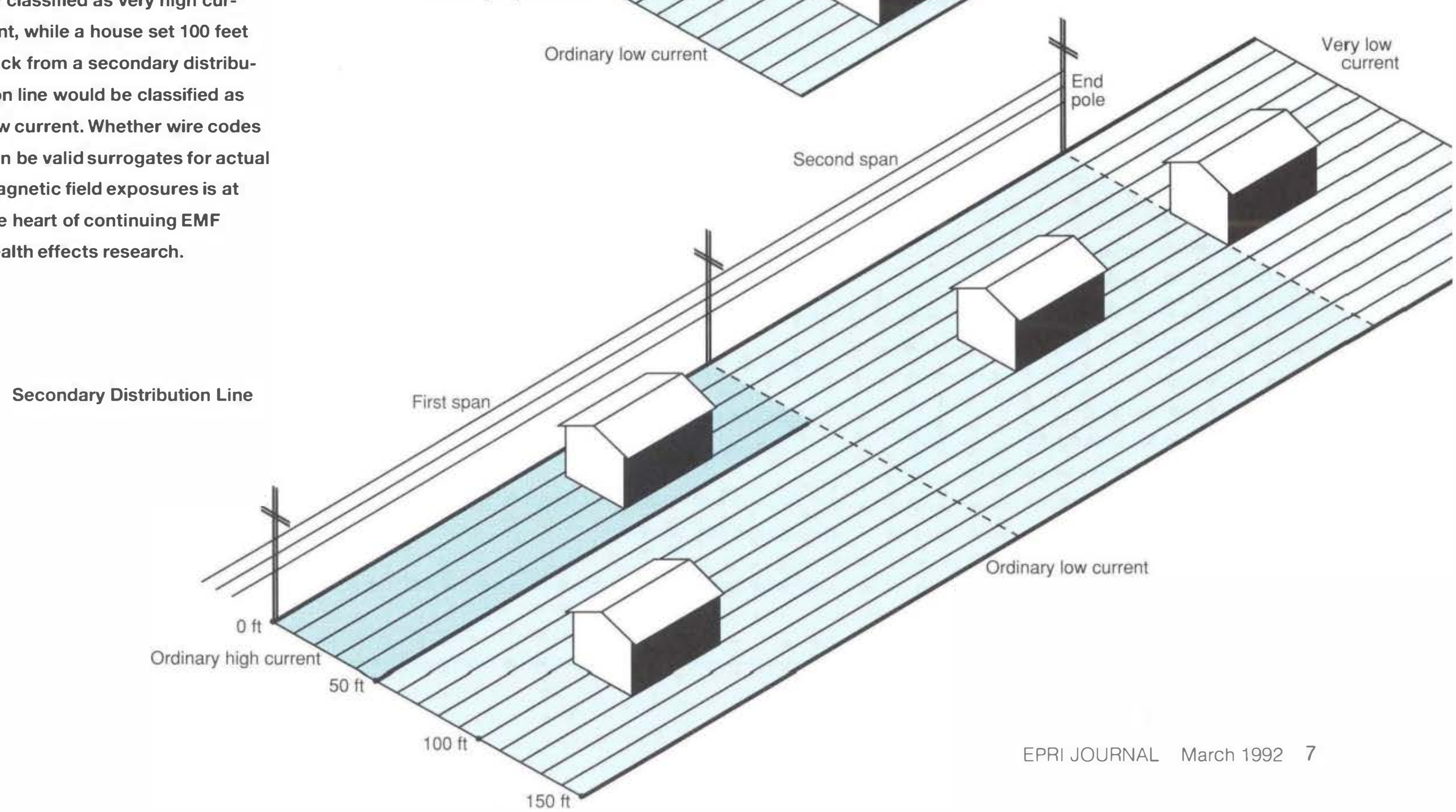
In a peer-reviewed report of the study's results in the *American Journal of Epidemiology*, the USC team said that their findings suggest two fundamentally different interpretations. One is that a true link exists between childhood leukemia and magnetic field exposure, as suggested by the association with wire codes. This would mean that spot and 24-hour indoor measurements of magnetic fields (including in the children's bedrooms) fail to accurately represent long-term exposure or to capture the aspect that is biologically significant, such as transients or the presence of both alternating (ac) fields and particular levels of the earth's static (dc) magnetic field. The researchers noted experimental evidence about such ac-dc interaction that "highlights the possibility that we are looking at the wrong measure of electric and magnetic field exposure."

A second interpretation is that childhood leukemia is not associated with magnetic field exposure, and that bias or confounders are behind the apparent association with high-current wire code classifications. Wire codes may be a surrogate for other factors—not magnetic fields—that may be associated with leukemia risk. But the USC researchers noted that their results were largely unchanged when other known leukemia risk factors were considered. While unknown risk factors might confound the results, the researchers noted, these factors "would need to be strongly associated with risk or extremely tightly correlated with wiring configuration classification to have

WIRE CODES: SURROGATES FOR MAGNETIC FIELD EXPOSURE? Wire code classifications were originally developed by researchers Nancy Wertheimer and Ed Leeper as a nonintrusive method of estimating indoor magnetic fields in their 1979 study of childhood cancer in Denver. Based on accepted principles of how magnetic fields levels are related to the levels of current in a conductor and the distance from the conductor, the code classifications take into account the number of lines present, the thickness of the conductors, how far out on a distribution circuit a house is located, and how far the house sits from the line. Thus a house situated within 30 feet of a thick-conductor primary distribution (or transmission) line would be classified as very high current, while a house set 100 feet back from a secondary distribution line would be classified as low current. Whether wire codes can be valid surrogates for actual magnetic field exposures is at the heart of continuing EMF health effects research.







produced the odds ratios in our study and others."

Selection bias caused by selective nonparticipation in the study also could produce an apparent association, they noted. A random telephone-dialing method was used to select controls. If more families who lived in high-current-classification homes declined for some reason to participate than other families, that could result in an apparent higher leukemia risk. This is one focus of follow-on EPRI-sponsored research at USC and other institutions to try to unlock the riddle of the wire code results.

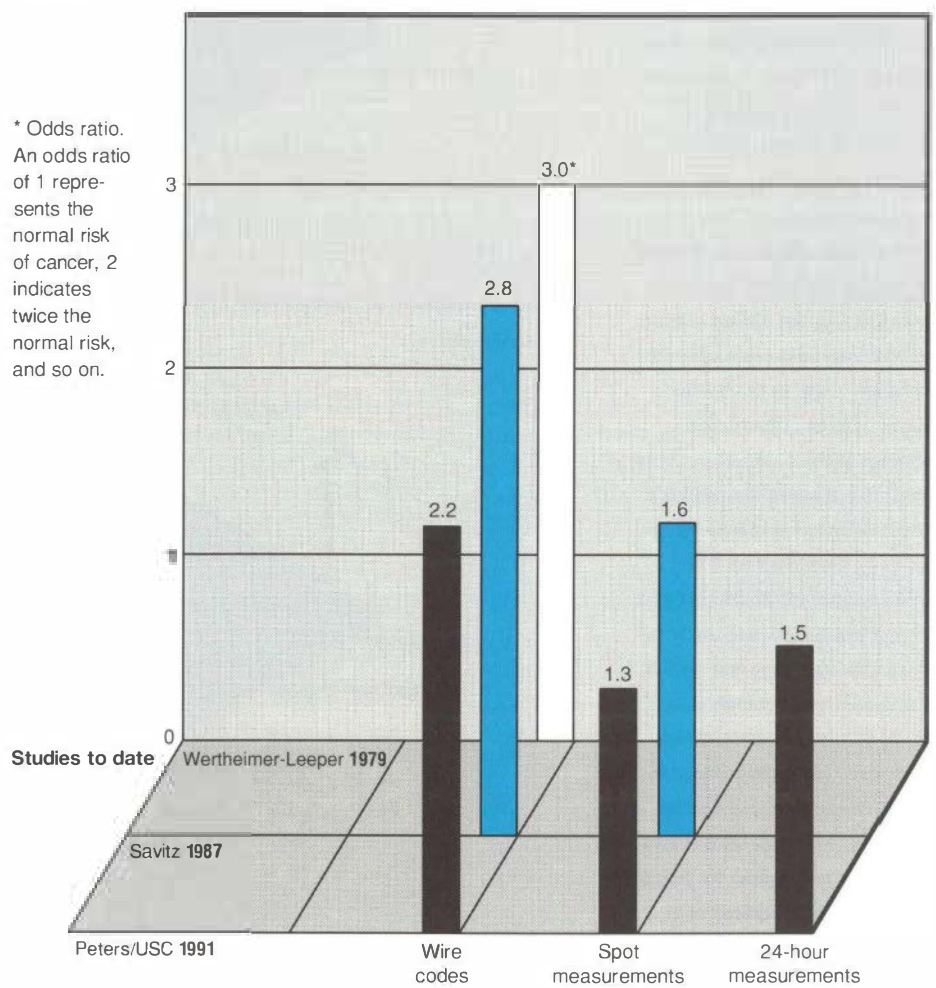
The contradiction vexes other experts who have long followed EMF research. "If we could know the answer to only one question right now, it would have to be, what do wire codes mean? To me, that is the greatest mystery we need to resolve," says Dr. Leonard Sagan, senior medical scientist for EPRI's Environment Division and former head of the division's EMF research program. "Epidemiological studies by three teams of investigators in two cities have observed an association between wire codes and childhood cancer," notes Sagan. "Although the meaning of the association is by no means clear, it does mean something. EPRI has placed a high priority on determining which of the possible explanations for it are true."

Future directions for epidemiology

According to Leeka Kheifets, an epidemiologist and project manager in EPRI's EMF Health Studies Program, "The USC study represents a considerable improvement over previous work in that it had a clearly testable hypothesis, a larger number and better participation of subjects, more extensive field measurements, and a good assessment of known confounding factors." But because of the conflicting findings, "the relationship between leukemia and magnetic fields remains unclear."

Kheifets adds, "The finding that 24-hour exposure measurements do not predict leukemia risk as well as wire codes indicates new directions for research, and the obser-

FROM WIRE CODES TO MEASURED FIELDS When some early epidemiological studies showed a statistically meaningful association between high-current residential wire code classifications and childhood cancer, researchers expected subsequent studies that included actual measurements of indoor magnetic fields (rather than the wire code surrogates alone) to show an even stronger correlation. Surprisingly, the association is significantly weaker. New work is planned to shed light on this enigma, including development of ways to measure transient magnetic fields as perhaps the more relevant type of exposure, and a search for clues that other causes of cancer may be confounding the apparent association with wire codes.



Future studies are expected to:

- **Conduct week-long indoor field measurements as possibly more indicative of past exposure**
- **Develop ways to measure magnetic transients, which may represent the biologically relevant field exposure**
- **Probe for possible other causes of cancer that may confound the wire code association**

vations regarding appliance use suggest the need for more emphasis on examining exposure to transient, high-level fields."

Researchers note that, because of differences in the electrical distribution systems in Denver and Los Angeles, the wire code originally used in the 1979 Wertheimer-Leeper study in Denver was not expected to predict magnetic fields as accurately in Los Angeles. It turned out that actual indoor measurements in Los Angeles correlated only roughly with wire code classifications—and not as well as measurements had in a second study in Denver that replicated the finding of an association with leukemia.

Yet there were notable differences in the pattern of wire code classifications between the cities. Los Angeles appeared to have a higher proportion of high-current-classification homes, but lower average measured magnetic fields, than seen in Denver. "That suggests it may not be the average field level, as we measure it today, that is important in explaining the association between wire codes and childhood leukemia," says Kheifets. "It's also possible that wire codes are somehow more predictive of past, long-term exposure than today's measured averages."

Follow-on EPRI-sponsored research at USC is focused on developing a wire code classification scheme for Los Angeles that is superior to Wertheimer-Leeper's Denver method as a predictor of indoor magnetic fields. The USC team said that if, for the Los Angeles data on childhood leukemia, an improved wire code is found to be more closely associated with risk than the Denver classification was, it would represent strong evidence that the confirmed association with the Denver classification approach reflects an underlying association with magnetic fields rather than bias.

An additional analysis at USC is focused on a hypothesized mechanism of interaction that requires simultaneous exposure to both alternating fields and the constant geomagnetic field. Laboratory studies at the cellular level first raised suggestions of such ac-dc interaction. The resulting hypothesis is known as the resonance hypothesis because the interaction is effective only for a narrow set of frequencies for a given value of magnetic field. To properly test the theory, studies may have to be done in several U.S. locations where the earth's field is more nearly resonant with 60-Hz ac fields.

Meanwhile, a related avenue in the search for answers regarding a link between childhood leukemia and EMF is focused on determining whether exposure increases the risk of recurrence among cases that have gone into remission. The case-control studies in Denver and Los Angeles used field measurements after the occurrence of leukemia to infer past exposures. But an EPRI-sponsored study of leukemia survivors, now in the pilot stage, will prospectively measure actual exposures as it tracks health outcomes over the next several years.

The recruitment of 25 leukemia cases for the present pilot study is being conducted at the Stanford University Medical Center in California, a member of the Pediatric Oncology Group, one of two ongoing national cancer study groups. The other major group of affiliated medical institutions involved in childhood cancer, the Children's Cancer Study Group, is collaborating with the National Cancer Institute in a six-state study of childhood leukemia that includes examination of magnetic field exposure. Begun in 1989 as part of a larger study of acute lymphocytic leukemia, the NCI study is not expected to be completed until 1995.

The interaction mechanism puzzle

Much of the scientific skepticism that has greeted epidemiological studies or laboratory evidence of a link between EMF and cancer has stemmed from the difficulty in imagining plausible mechanisms by which weak, low-frequency EMF from common sources could effect biological changes. It is widely accepted that these levels of EMF do not cause genetic damage.

Most proposed mechanisms for EMF biological interaction have some logical gap or require highly speculative assumptions to hold together, experts say. Yet there is one model—the melatonin hypothesis—that has been explored for some time and perhaps goes further than any other toward receiving a measure of broad acceptance. Several assumptions on which it depends have yet to be demonstrated. But recent rat experiments have shown that certain magnetic field exposure conditions may suppress the production of this hormone. The experiments have sparked an urgent quest to determine, first, the specific conditions under which the effect occurs; second, whether similar effects occur in humans under realistic exposures; and third, whether such effects are relevant to cancer.

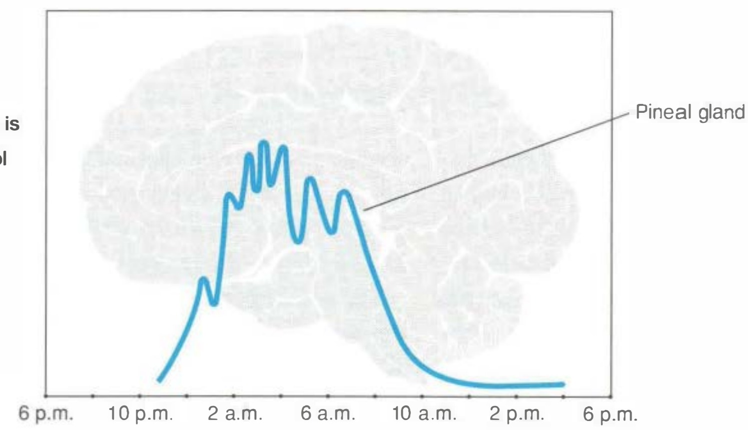
Melatonin is produced in all vertebrates at night by the brain's pineal gland, which in humans is about the size of a pea. The hormone's synthesis by this gland, part of the brain's visual response system, is triggered by darkness and peaks in the middle of the night in a rhythm set by the daily light-dark cycle. Melatonin travels throughout the body via the bloodstream, carrying chemical information about the time of day and season—information that affects many other biological rhythms. It's known that human exposure to strong light at night can suppress the production of melatonin and alter circadian rhythms. And scientists say it is possible that magnetic fields are perceived through the retina as light.

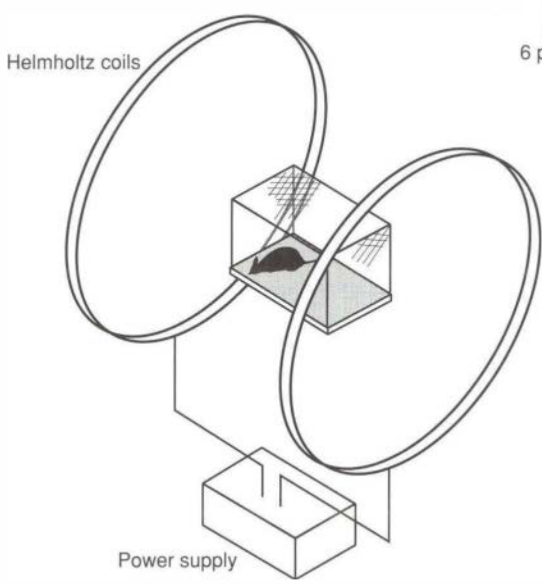
According to Russel Reiter, a professor of neuroendocrinology at the University of Texas Health Sciences Center in San Antonio, whose experiments with rats are behind much of the recent interest in melatonin among EMF researchers, disruption or suppression of the hormone's normal rhythms in humans could potentially have a number of physiological consequences. These could include altered mood, fatigue and lethargy, disturbed circadian rhythms (e.g., sleep disorders), changed reproductive and endocrine function, and deficient immune responses, as well as increased cancer risk.

Moreover, Reiter adds, "many of the currently described effects that allegedly occur in animals as a consequence of magnetic field exposures, particularly reproductive

MELATONIN SUPPRESSION: A PLAUSIBLE MECHANISM OF INTERACTION Recent experiments with rats have raised new interest in whether human exposure to magnetic fields suppresses the nighttime production of melatonin, a hormone that may affect the body's immune system. Such an effect, observed in rats, has been suggested as a plausible pathway by which magnetic fields could be involved in the development or promotion of cancer. The hormone, meanwhile, is being studied for its ability to inhibit the growth of certain tumors.

Melatonin synthesis in the brain's pineal gland is triggered by darkness and is thought to control many biological rhythms.

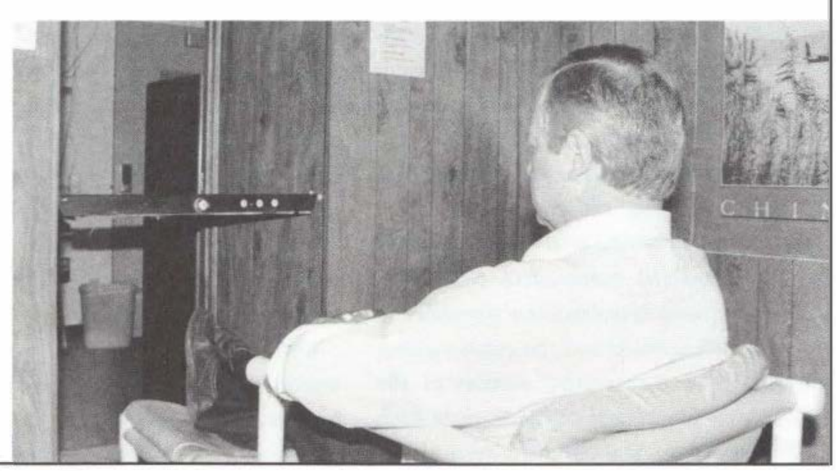




Rat experiments show suppression of melatonin synthesis with exposure to rapidly varying pulses of dc magnetic fields; new work will probe whether the effect occurs with alternating fields more like those to which people are exposed.

EPRI is planning the first human experiments using volunteers exposed to alternating magnetic fields under controlled laboratory conditions to investigate whether such exposures affect human melatonin synthesis.

Midwest Research Institute



and cancer effects, could be—not necessarily are, but could be — explained on the basis of an alteration in melatonin production. Melatonin influences virtually every one of the parameters in which EMF has been shown to have an effect."

Reiter notes clinical experiments in which melatonin is being tested as a potential inhibitor of tumor growth. If, as suggested, EMF exposure is associated with the incidence of tumors or cancer, "it could be—and I underline that again, it *could* be—a consequence of reduced melatonin production. At this point, it's a theory that is no more than a working model, but it gives us something to hang our hat on and represents a plausible mechanism of interaction."

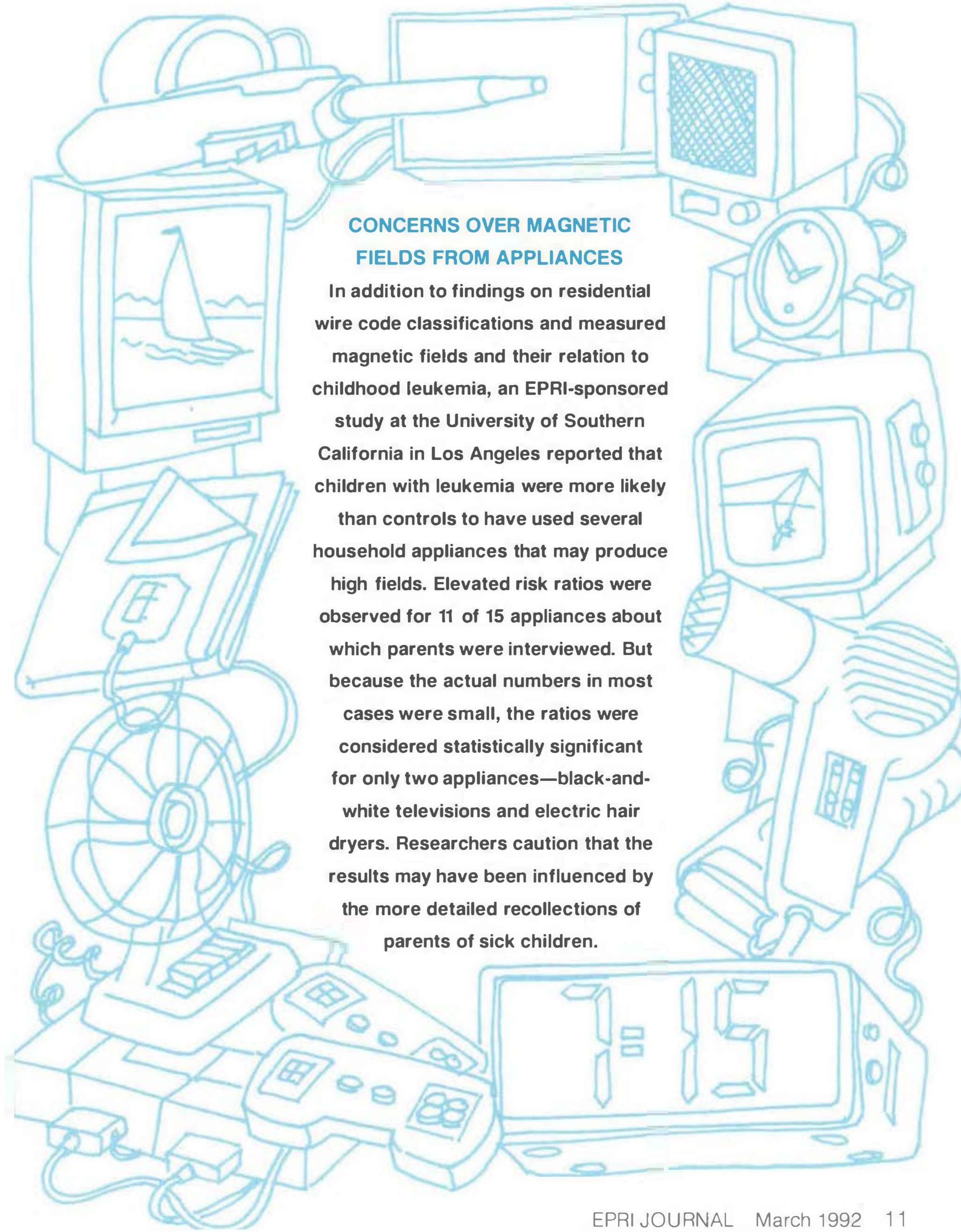
In Reiter's experiments, rats were exposed at night to pulsed dc magnetic fields of 200 to 400 milligauss that effectively inverted the geomagnetic field around them at 1-minute intervals for about an hour. Significant reductions in the pineal gland's melatonin production were observed. Induced current transients without inversion of the geostatic field failed to suppress melatonin synthesis. While these laboratory observations bear little resemblance to real-world exposures, they do suggest that rapid changes in fields could be biologically important.

EPRI is funding follow-on work by Reiter to explore in greater detail the technical parameters and the conditions of field exposure that are involved in the suppression of melatonin in rats. Researchers are obviously interested in seeing whether the effect can be reproduced under conditions that more closely resemble human exposures to ac fields. Reiter is also pursuing for EPRI more in-depth studies to define the physiological mechanism for melatonin suppression in rats. He says it is also conceivable that alteration of the level of some hormone other than melatonin, as yet unknown, is the real mechanism of EMF interaction.

EPRI plans to sponsor new research related to Reiter's work, possibly including efforts to replicate the rat experiments. The continuing effort is part of the diverse basic sciences component of the Institute's EMF Health Studies Program. Earlier studies at Battelle, Pacific Northwest Laboratories, that reported a suppression of melatonin in rats exposed to electric fields sparked much of the original interest in this line of inquiry. Recent basic sciences work supported by EPRI at the University of Rochester, however, failed to reproduce this result. EPRI is also sponsoring experiments at the cellular level by Battelle, using cultures of cells—pinealocytes—from the pineal glands of chicks to study the rhythms of melatonin synthesis.

Reiter and other researchers are quick to stress the danger of prematurely extrapolating an effect in rats to humans. A critical question, then, is whether melatonin synthesis in humans is also suppressed by magnetic field exposure. A limited study of human volunteers and home electric blanket use, conducted for EPRI by Battelle in 1988, was inconclusive in identifying such an effect. New studies of subjects at sleep under controlled laboratory exposure conditions, however, are expected to more clearly test the hypothesis.

The experiments are planned to get under way this spring at the Midwest Research Institute facility in Kansas City, Missouri. Researchers in recent DOE-sponsored



CONCERNS OVER MAGNETIC FIELDS FROM APPLIANCES

In addition to findings on residential wire code classifications and measured magnetic fields and their relation to childhood leukemia, an EPRI-sponsored study at the University of Southern California in Los Angeles reported that children with leukemia were more likely than controls to have used several household appliances that may produce high fields. Elevated risk ratios were observed for 11 of 15 appliances about which parents were interviewed. But because the actual numbers in most cases were small, the ratios were considered statistically significant for only two appliances—black-and-white televisions and electric hair dryers. Researchers caution that the results may have been influenced by the more detailed recollections of parents of sick children.

Epidemiology: Focus on Other Exposed Groups

The search for clues of a possible causal link with EMF in the incidence and pattern of cancer is being conducted on a broad front in various study populations. Concern about EMF exposures during vulnerable stages of human development extends not only to children but to the fetus. Some studies have reported evidence of EMF effects on reproductive outcomes. In addition to studies of childhood leukemia, other EPRI-sponsored EMF epidemiology is under way at Yale University, where medical researchers are monitoring the magnetic field exposures and electric blanket use of some 3000 pregnant women. Early results of the Yale study should be available next year and are expected to complement the results of a study by California health researchers of spontaneous abortions and EMF exposure that may be completed this year.

Meanwhile, one category of people whose EMF exposure has been assumed to be higher than average is workers in the so-called electrical occupations and related professions. Such workers are often near high-voltage apparatus and other equipment carrying or producing large amounts of current and thus may be exposed to strong magnetic fields. On the basis of analyses of disease and death rates according to job title (as indicative of exposure history), a number of studies have suggested increased risk of leukemia and brain cancer among such workers. Until recently, there were few actual measurements of occupational exposures to magnetic fields, but several EPRI-sponsored studies have substantially reduced the deficit.

EPRI has also sponsored work by a group at the University of Southern California to reexamine the results of previous job title studies of leukemia among electrical workers in this country and in New Zealand, incorporating exposure

and potential confounder data from actual on-the-job measurements. Final results from that work may be reported early this year, says Leeka Kheifets, the project manager. "In general, this study and other measurement studies by EPRI have confirmed that many so-called electrical jobs do entail higher EMF exposures on average," she says.

Extensive measurements of personal exposures were made for various telephone company jobs in recent occupational studies for EPRI by researchers at Johns Hopkins University. Telephone workers, who had been thought to receive magnetic field exposures comparable to those received by utility line workers, in fact generally received little exposure; the exceptions were cable splicers and also central office technicians who worked near older, electromechanical switching banks.

The nationwide leukemia study of 461 current and retired telephone workers found little correlation between magnetic field exposure and leukemia risk. More-specific analyses, however, in which exposures were calculated in different ways (by job title, by measured average field, by measured peak field), reported elevated risks among younger, active employees exposed to relatively high peak fields for extended periods. But because the number of these subjects was small, the risk was uncertain.

Whether there are increased cancer risks discernible among workers known to be occupationally exposed is being asked in one of the largest studies of its kind yet conducted. It encompasses up to 135,000 workers at five major U.S. electric utility companies. Begun in 1989, the study is past its midpoint and should report results by the end of 1993. It is being conducted for EPRI under the direction of David Savitz, a University of North Carolina epidemiologist. Savitz headed the second Denver study, which confirmed the original report of an association between residential wire codes and childhood leukemia.

Savitz says that, unlike most previous studies of occupational EMF exposure, the EPRI-funded investigation of electric utility workers includes extensive actual measurements of magnetic fields. The measurements will be used to reconstruct and estimate employee exposure histories through job title classifications. Employee exposures to potential confounding risk factors in the work environment, such as chemical solvents and polychlorinated biphenyls, are also being considered. The study should be able to discern differences in cancer rates between groups of workers with different levels of magnetic field exposure.

"It's clear from our data and other information that the intuition that linemen and others who work around energized equipment have elevated exposures is indeed correct," says Savitz. "Our study includes enough of these workers to allow us to try to answer the basic question of whether their occupational EMF exposure history is related to the risk of leukemia and brain cancer."

Robert Black, the EPRI project manager, says that the utility workers study is turning out to be more statistically robust than planned because it includes a larger number of retired workers than expected, among whom the number of deceased will be four times the expected number. "We originally thought we would have on the order of 5000 deaths, but it looks like there will be about 20,000," he explains. "This stems from there being more—and older—retired workers than were expected when the study was planned."

The results of Savitz's study are expected to be released at around the same time as those of a similarly large study of Canadian and French utility workers that is under way at McGill University in Montreal. "Together, the U.S. and Canadian studies should give a clearer picture as to whether workers in the electric power industry face a risk of leukemia or brain cancer due to magnetic field exposure," says Black. ■

work at the MRI facility have been the first to observe and report specific, reproducible physiological effects (namely decreased heart rate and slower evoked response to stimulus) in human subjects under exposure to moderately high magnetic fields.

Robert Black, the EPRI project manager for the melatonin-sleep studies, says the first experimental series, involving 15 to 20 subjects, will perhaps be completed by November of this year. Researchers will look for evidence of threshold levels and dependence of suppression effects on magnetic field exposure patterns.

Meanwhile, a study at the University of Washington's Fred Hutchinson Cancer Research Center is expected to begin soon. With funding from the National Cancer Institute, the study will investigate the hypothesis first proposed by Battelle epidemiologist Richard Stevens that EMF-induced suppression of melatonin may also be involved in some cases of breast cancer. Stevens says the link was suggested to him by studies reporting melatonin suppression and is lent more credence by evidence in several epidemiological studies of an increased risk of male breast cancer associated with occupational magnetic field exposure. The Hutchinson Center's breast cancer study is expected to include 700 to 800 cases and a like number of controls, and to take about four years to complete.

Other directions for research

The sharper focuses on wire codes in epidemiology, on melatonin suppression, and on magnetic field transients in general are examples of how recent results are informing ongoing studies and affecting plans for future investigations. Another key example, in the area of basic laboratory studies, involves plans under way at EPRI to sponsor efforts to replicate the results of a Canadian study on the promotion of skin cancer in mice.

Government researchers in Ontario recently reported that magnetic fields act synergistically with a chemical that is a known tumor promoter to accelerate the development of skin tumors in mice. The preliminary results are believed to be the first to directly link magnetic fields with the development of cancer in animals. Work to replicate and extend copromotion studies was given the highest priority last fall at a high-level cancer research workshop held to offer guidance on EPRI's basic science studies in EMF, according to Charles Rafferty, project manager.

EPRI's comprehensive R&D program reflects the high priority the Institute's electric utility members assign to both accelerating EMF research and positioning the industry to respond in the most intelligent manner possible if any health risk is found. The program spans all aspects of the EMF issue—from health effects and laboratory studies, to instrumentation and field measurements, to analytical hardware and software, to electrical engineering, including potential field management measures.

Despite the growing research interest and activity in EMF health studies beyond EPRI, the Institute's expanding program continues to be the largest and most sustained effort in the world, Stanley Sussman notes. "EPRI's program will remain very important within the overall national effort that is taking shape, but we are encouraged by the new movement to get a coordinated approach that will bear down on the key questions about EMF." ■

Further reading

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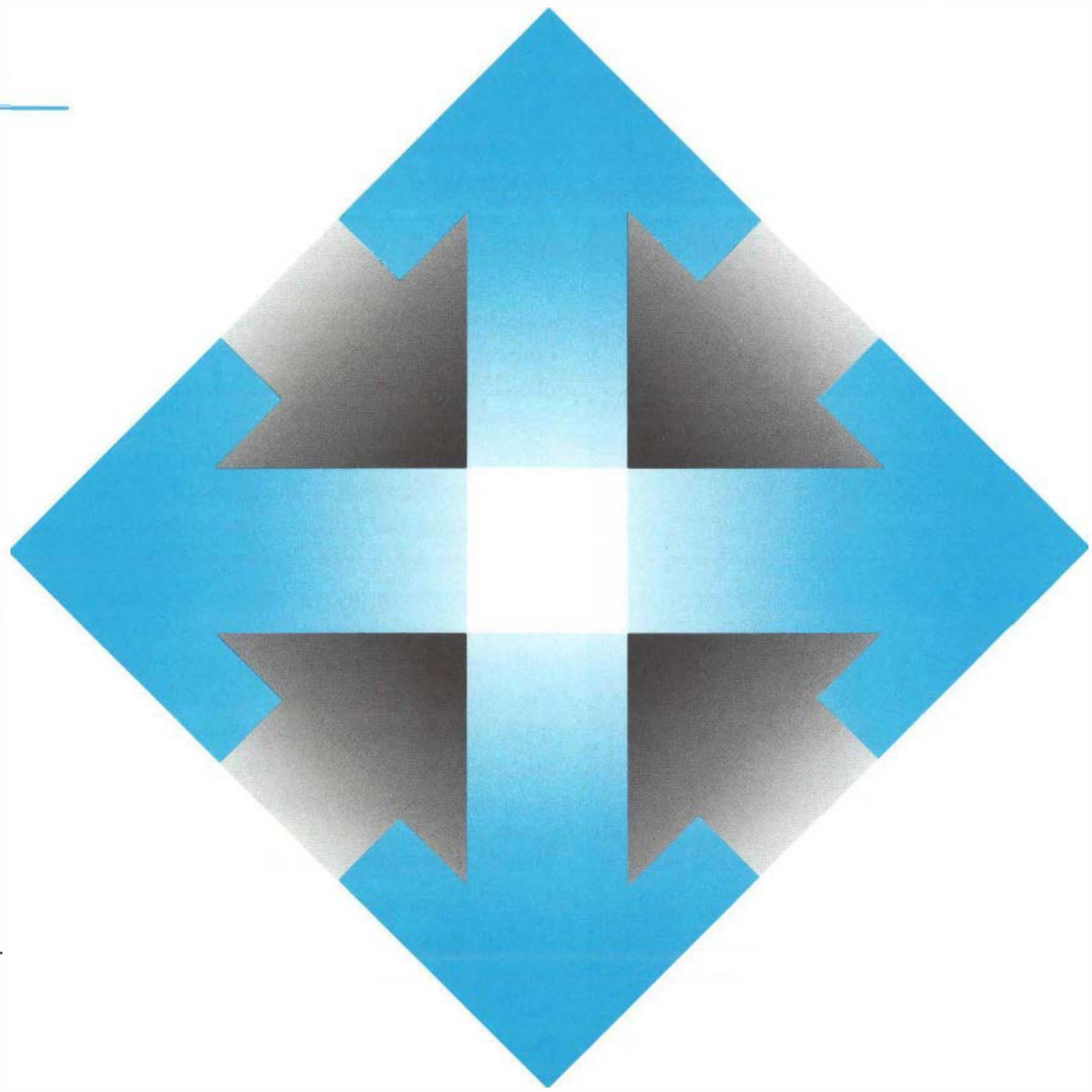
This article was written by Taylor Moore. Background information was provided by Robert Black, Leeka Kheifets, Charles Rafferty, Leonard Sagan, and Stanley Sussman, Environment Division.

by Brent Barker

ENERGY EFFICIENCY
Probing the Limits,



Expanding the Options

THE STORY IN BRIEF

Energy efficiency has been one of the great energy success stories of the last quarter century. Dismissed by many in the 1970s as having very limited potential, it has proved to be a potent force in every end-use sector and now demands a central position in any serious discussion of energy planning. But while tapping the "efficiency resource" has become a theme embraced by such widely disparate groups as consumers, industry, policymakers, environmentalists, energy experts, and utilities, the business of energy efficiency is getting down to hard, practical questions. What incentives would increase its attractiveness to energy users? What is its value to society, and who should pay its costs? How great an influence can it have on burgeoning environmental concerns? These and other issues sparked spirited discussion at the most recent EPRI Summer Seminar, which attempted to shed light on efficiency's place in our energy future.

TWO DECADES AGO, energy efficiency was an obscure concept for most Americans. Labor efficiency and technical efficiency were the central measures of American economic life, while energy was relegated to a support role. Abundant and cheap, energy was often seen as a marginal commodity to be used—lavishly if necessary—in the pursuit of comfort and convenience and, in the case of industry, to spur higher and higher production efficiencies from labor and capital. But energy's obscurity ended with the oil shock of 1973. Not only did the headlines and prices change, but so did the perceptions, policies, and pursuit of energy efficiency.

Today energy efficiency is big business, by one estimate yielding net savings to the U.S. economy of $135 billion per year as a direct result of the conservation measures put in place since 1973. This means that roughly one-third of the total U.S. energy bill has been essentially freed up and diverted to more productive use in other parts of the economy. And today there is good and growing reason to believe that the economic potential for energy efficiency has barely been tapped. In fact, the pace of technical advancement in materials, sensors, controls, lighting, windows, motors, appliances, and a vast array of electrotechnologies has become so rapid that the long-term potential of what is now called the efficiency resource is opening wide—running years, if not decades, ahead of market reality.

Energy efficiency has also become big politics. The benefits are so broad-based and so appealing that the banner of energy efficiency has become something of a unifying theme among widely disparate groups—consumers, industry, policymakers, environmentalists, energy experts, and utilities—who, at least for the moment, find themselves sharing a common pathway toward divergent goals. Energy efficiency is now widely recognized as a boon to the economy, providing savings to the consumer, competitive advantage to the producer, and profit to the shareholder. Moreover, energy efficiency has also acquired the mantle of being the fastest, cheapest, and perhaps most durable route to environmental protection. As a result, it has become a cornerstone of policy formulation in the last five years at the state, the federal, and even the global level, as governments grapple with the interlocking issues of economic development and environmental protection. In 20 short years, energy efficiency has gone from relative obscurity to being nearly everyone's favorite solution to the future of the world.

In many ways, the 1990s may turn out to be the golden age of energy efficiency, a time of glowing promise, initial success, and nearly universal support—a time when all things are still possible. Whether energy efficiency can ever live up to this promise remains to be seen. Although there is nearly universal praise for both the benefits and the social necessity of energy efficiency, questions still abound, forecasts vary all over the lot, and impatience and skepticism seem to square off against each other. Some proponents want to alter current market forces to speed the adoption of energy-efficient technology; others caution against price distortions that may pop up as inefficiencies in other parts of the economy. Many express concern that energy efficiency is quickly becoming an end in itself, something easily oversold, a panacea that like other, earlier illusions in the energy business may simply fade away in the light of time and reality. Still others are quietly going about the business of putting energy efficiency into practice.

It was against this backdrop that the EPRI Board of Directors, the Institute's Advisory Council, and their guests convened the 1991 EPRI Summer Seminar—"Energy Efficiency: Probing the Limits, Expanding the Options." Over 60 leaders from utilities, industry, government, academia, and the regulatory and environmental communities met to explore the unfolding possibilities and pitfalls in energy efficiency. At issue were the true nature and scale of opportunity, the evolving role of electricity in achieving both energy efficiency and economic efficiency, and the lessons to be drawn from the hard-won experience of utilities and regulators in pioneering demand-side management and other efficiency programs. Seven speakers sparked two days of spirited discussion that swept across the terrain of lessons learned, forecasts, new technology, market barriers, incentives, policy direction, and the role of research.

The great potential

John Sawhill, president and CEO of the Nature Conservancy, kicked off the seminar by laying out the basic opportunity and challenge for the nation: "Rarely are we presented with an opportunity that really profits the environment, consumers, and producers alike. The opportunities are enormous. Using existing technology to achieve rigorous efficiency measures, we could save between one-third and one-half of all energy in this country. And the potential savings for electricity are still higher—around 70%."

As large as they are, these figures are for the most part consistent with the conclusions reached by the National Academy of Sciences and the Office of Technology Assessment in their recent studies on climate change. But they are not forecasts so much as statements of potential. The question raised by many is whether these kinds of savings can be realized at reasonable cost. After all, such massive savings would require tremendous investments in energy-efficient buildings, equipment, vehicles, and industrial processes—investments in the tens or perhaps even hundreds of billions of dollars, seemingly beyond the capability of a recession-strapped economy. But according to Arthur Rosenfeld, director of the Center for Building Science at Lawrence Berkeley Laboratory and a contributor to both the NAS and OTA studies, these investments would for the most part be fully recovered by the savings in energy. In fact, many of them would make money.

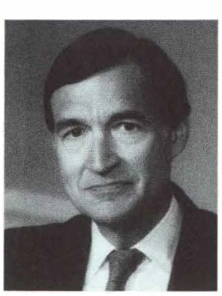
"All of the last four serious studies pretty much agreed that the potential is there—that we can save about 50% of our primary energy at a net economic benefit," said Rosenfeld. "Our work on the NAS study showed a number of areas for large-scale improvement. Improving the energy efficiency of our buildings was found to be the area with the largest potential, followed by improving vehicle efficiency, and then industrial efficiency. We estimate the net economic savings from these three areas alone at $82 billion a year."

The kinds of benefits Rosenfeld envisions stem from the vast array of technological improvements in materials and electronics achieved over the last two decades, which have influenced a whole new generation of energy-efficient products, ranging from low-emissivity windows to compact fluorescent light bulbs. Some advances employ exotic new materials with staggering thermal insulation properties; others simply involve reengineering of basic appliances, machines, and processes. As an example of the kind of progress that might be achieved, Rosenfeld pointed to some very tangible results over the last few decades. He noted that the most popular refrigerator sold in California in 1975 was an 18-cubic-foot model that consumed about 1790 kWh a year; today the most popular model is 10% bigger but consumes less than half the energy—about 800 kWh a year. Similarly, he noted, the average car today gets about 28 mpg, double the average rate in 1975.

Nevertheless, the market response to energy-efficient technology is surprisingly sluggish. As some of the participants pointed out, the pace of development in energy-efficient technology is now so rapid that it has in many ways quickly outdistanced the marketplace. Capital equipment turns over slowly, consumer buying patterns are not tied strongly to questions of energy, and the incentives for energy savings are often confusing, contradictory, or not apparent.

Clark Gellings, then director (now vice president) of EPRI's Customer Systems Division, added quantification to the consensus: "According to our studies, consumers make purchase decisions on the basis of 16 attributes of service, of which cost ranks in the middle and concerns about efficiency are near the bottom. The technical potential is definitely there—efficient end-use technology could theoretically reduce the projected electric energy demand for the year 2000 by 24–44%. But to achieve this level of savings, all of these technologies would have to be introduced immediately and have 100% penetration in the marketplace. With market barriers the way they are, we know that will just not happen."

Sawhill also acknowledged the disparity between the efficiency potential and the market reality. "All these glowing projections of energy savings are meaningless unless we bring the market barriers down," he said. "These barriers run the gamut from limited access to capital, to uncertainty in fuel prices, to regulatory policies, consumer attitudes, information gaps, and perceptions of risk and benefit. Nevertheless, I believe the key to reducing these barriers is to provide consumers with the proper incentives to conserve. We must accept that consumers in this country have short payback horizons—they typically want to recover their investments in less than two years."



"Rarely are we presented with an opportunity that really profits the environment, consumers, and producers alike. The opportunities are enormous. Using existing technology to achieve rigorous efficiency measures, we could save between one-third and one-half of all energy in this country. And the potential savings for electricity are still higher—around 70%."

JOHN SAWHILL

Since market barriers remain formidable and, in the view of most observers, are likely to retard the adoption of more-efficient technologies for years, Sawhill cautioned the participants "not to overpromise or overrepresent what can be achieved with energy efficiency. Twenty-five years ago the reigning orthodoxy held that nuclear was our salvation for energy problems. I think it is possible, even likely, that similar questions will come back to haunt us about energy efficiency. We should be prepared with answers when this happens—and to the extent we can, we should measure and document what is being spent and what is being achieved."

Electrification a key to savings

Sawhill, Gellings, and others believe that one way to enhance the move toward energy efficiency is through further electrification. Historically, they noted, nations have been drawn to electricity to advance the efficiency of their entire economies—from labor to raw materials processing, to manufacturing, to agriculture. Energy efficiency, which grew dramatically in virtually all the developed nations as electrification spread, was in many ways just an afterthought, a by-product of the drive toward economic productivity. But today it has moved to the foreground of strategic considerations.

Most seminar participants were willing to advance electrification as an explicit strategy to accelerate energy efficiency and improve the environment. Sawhill, for one, is convinced that "there is much greater potential for savings in the use of electricity than in the use of energy in general, because electricity is so versatile. There is simply more value in a Btu of electricity than in a Btu from another energy source. This is not well understood. People just don't distinguish between Btus from different energy sources."

Clark Gellings spent some time making the distinction clear. Taking a total-systems approach to energy use, he provided a number of examples to reveal how electricity's form value more than compensates for the energy loss in converting from primary energy to electricity in the first place, giving electricity a clear edge over the direct use of primary energy. In essence, the flexibility of electricity at the point of use allows it to do things in ways not possible with other fuels. Sending a letter cross-country electronically by fax machine, for example, costs about 10 Btu a page, mainly in the electricity that powers the machine and the telephone infrastructure. Sending the letter by courier costs about 200 Btu a page because of the fuel for air and ground transport. Overall, using fax technology is about seven times as energy-efficient as the courier approach.

Gellings presented several other examples that are more closely tied to utility concerns. Freeze concentration techniques for extracting water are about twice as efficient as evaporation processes, he noted. And electric vehicles are potentially twice as efficient as gasoline-powered vehicles on a per-mile basis. But perhaps the most impressive illustration of the form-value advantage is the emergence of the electric heat pump, which now competes successfully in applications that have long been dominated by gas-fired equipment.

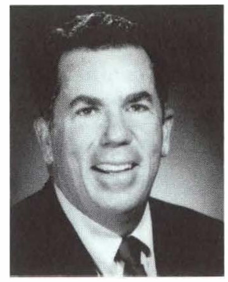
"The heat pump is a true solar heating device," Gellings said, "where electricity makes it possible to extract and use the heat from the natural environment in the most efficient manner possible. Today, with the Carrier-EPRI Hydrotech 2000 heat pump, which has a coefficient of performance of 3.4, the total-systems efficiency is conservatively stated at 99%. From an energy point of view, this is better than the best pulse-combustion gas furnace on the market. And in the future, as the efficiencies of heat pumps climb and as efficiencies in the production and delivery of electricity also advance, we can expect total-systems efficiencies to move well above 100%. For this reason, I see the heat pump as an opportunity to decrease the nation's energy use."

Gellings also drew a distinction in savings between the "wiser" use and the "wider" use of electricity—that is, between improving the efficiency of existing applications, on the one hand, and developing new, inherently more efficient applications, on the other. His point was that significant energy savings arise from electricity use in two stages—first, with the initial substitution of electrotechnologies for primary energy and, subsequently, with the stream of innovations opened up by linking electrotechnologies to electricity-based microprocessors and computer control systems.

Gellings predicts that the wiser use of electricity will save the United States about 450 billion kWh of electricity by 2010, but that its wider use—in new applications for industry, commercial establishments, vehicles, and the home—will add about 700 billion kWh to U.S. electricity demand by then. The net result will be an increase of 250 billion kWh. But since both the wiser and wider components reduce primary energy requirements, the overall savings will be a 12.2-quad reduction in annual energy use, and the savings to the environment will be a reduction in carbon dioxide emissions of 685 million tons per year.

"The technical potential is definitely there—efficient end-use technology could theoretically reduce the projected electric energy demand for the year 2000 by 24–44%. But to achieve this level of savings, all of these technologies would have to be introduced immediately and have 100% penetration in the marketplace. With market barriers the way they are, we know that will just not happen."

CLARK GELLINGS

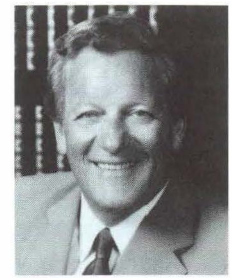


"Yes, energy efficiency is in fact good business. As a business strategy, efficiency gives us an alternative to expensive new plants, it improves our load factor, it reduces our financial risk, it provides us with a clean option, and our customers like it. Our customers like the rebates, credits, and other incentives. It's a win-win strategy."

ALLEN KEESLER

''Both supply- and demand-side efficiencies constitute an essential social response to environmental and economic pressures. Efficiency is no longer equated just with more kilowatthours per Btu consumed; it's equated with more total electric service for all resources consumed. In a business sense, efficiency adds value to our product and can be used to meet competitive threats.''

JOHN ROWE



Making it work in the real world

It's one thing to talk about energy efficiency in the abstract, quite another to make it work in the real world. How do we make it happen? How do we achieve the benefits? Those were some of the central concerns for many seminar participants. Most utilities in the United States are slowly feeling their way into the energy efficiency business—by rough count there are now some 500 utilities engaged in 1000 or more energy efficiency programs. But there is a growing sense that this is just the early stage of something far more sweeping. Some utilities are experimenting because of prodding by regulators or by environmental and consumer advocacy groups; others are moving aggressively because they sense both new opportunities and responsibilities inherent in energy efficiency. But at the leading edge are a number of pioneering utilities who recognize the profound transformation in utility thought now unfolding—a transformation focused on customer value and service—and who are turning it into a business strategy.

"Yes, energy efficiency is in fact good business," said Allen Keesler, president and CEO of Florida Power Corporation (FPC). "As a business strategy, efficiency gives us an alternative to expensive new plants, it improves our load factor, it reduces our financial risk, it provides us with a clean option, and our customers like it. Our customers like the rebates, credits, and other incentives. It's a win-win strategy."

John Rowe, president and CEO of New England Electric System (NEES), agreed. "Both supply- and demand-side efficiencies constitute an essential social response to environmental and economic pressures. Efficiency is no longer equated just with more kilowatthours per Btu consumed; it's equated with more total electric service for all resources consumed. In a business sense, efficiency adds value to our product and can be used to meet competitive threats."

Regional differences are proving crucial in determining the kinds of energy efficiency programs leading utilities pursue. FPC now has the largest load management program in the nation, involving a total of 380,000 customers who have individually chosen to have their air conditioning, strip heating, water heating, and pool pumps controlled in some predetermined way by the utility's radio system. Consumer rebates are on a per-appliance basis and depend on the amount of time the appliance is turned off. Air conditioning and heating are typically controlled 15 minutes out of each hour, although some customers prefer the 30-minute option. Water heaters can be turned off for longer periods—up to several hours—without inconvenience, according to Keesler. The real draw for the program, he said, is that "our customers like the opportunity to get rebates that can lower their bills by 15%, and more and more are taking advantage of these programs."

The results give FPC a constructive alternative to expanding supply in its fast-growing service territory. "We now control about 800 MW of load," Keesler said. "And by the turn of the century, when our demand doubles, we should be controlling about 2200 MW. For us this represents a plant not built. By the year 2000, we expect to reach saturation with our load control program at about 65% of our customers."

John Rowe's company has been a pioneer in implementing demand-side management programs in New England. NEES spent $106 million, or 5% of revenues, on the subsidy of DSM in 1991, which now makes its program "the most pervasive in the nation," Rowe said. The subsidies have more than tripled since 1989, justified largely by estimates that energy efficiency could be bought at the customer level for prices ranging between 3¢ and 12¢ per kWh, with typical prices in the range of 4–6¢ per kWh.

"We now have the first year of field data on how these programs really work," Rowe said. "The results vary widely. The socially most significant program, the one for low-income residential users, had the worst results. At the other extreme were the commercial lighting programs; these were very powerful, very successful. The upshot of what we learned is that demand-side efficiency has tremendous potential, but that customers often know something we don't know and we should respect that."

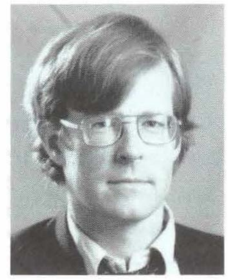
Utilities and customers have very different requirements for payback when making decisions about investing in energy-efficient technology. (Utilities use discount rates of about 12% a year, while customers, seeking faster payback, use discount rates of around 40% a year.) A few years ago, NEES installed some energy-efficient machinery and lighting at a local manufacturing plant, basing the decision on its own 12% rate hurdle. The following year the plant closed. "There is a powerful lesson in this," said Rowe. "We should have paid more attention to the customer's judgment. When it comes to the disparity in discount rates, my suspicion is that the customer is closer to right."

Sharing the savings

At the heart of the new focus on the customer is the economic health of the service territory and, by extension, the nation. "Ad-

"If we don't try the exciting, innovative rate structures, I think we face an erosion of public confidence in our industry. We need to get away from supply-based rates, away from broad averages, and to design rate structures and programs that reflect the true cost of each kilowatthour. In fact, conservation should become a profit center for many of us."

MARK DeMICHELE



"I can't overstate the importance of CO_2 as an issue. It looms above all other environmental consequences of electricity generation because it is the one totally unregulated pollutant. Costs associated with all other major pollutants have been incorporated in some fashion into the price of electricity."

RALPH CAVANAGH

vances in energy efficiency are crucial in improving the nation's productivity," said Mark DeMichele, president and CEO of Arizona Public Service Company. "Our own strategies tie directly to our customers. When we advocate energy efficiency as a business strategy, we're urging our customers not just to use less but rather to strategically manage their own energy resources."

In DeMichele's mind, one key to making this customer-driven strategy work is to test and reform utility rate structures: "If we don't try the exciting, innovative rate structures, I think we face an erosion of public confidence in our industry. We need to get away from supply-based rates, away from broad averages, and to design rate structures and programs that reflect the true cost of each kilowatthour. In fact, conservation should become a profit center for many of us."

Many utilities and state commissions are now borrowing ideas from one another, experimenting with rates and various incentives to enhance the adoption of energy-efficient technologies by utility customers. One concern is whether the demand-side investments should be rate-based, as capital assets traditionally are, or expensed, with some formula allowing customers and utilities to share the savings.

John Rowe is adamant on the shared-savings approach. "Rate-basing of conservation is anathema. We have been absolutely adamant in saying our leadership in conservation requires that we have the ability to currently expense our conservation programs, and that our profits be a shared-savings feature. In all three states we serve, we have a shared-savings formula. We earn 10% or so on the amount we spend."

The 50-state laboratory of utility rate experimentation is still a long way from resolution. One problem is that utility expenditures for conservation typically involve a complex set of cross subsidies to jump-start various programs; future participants will be asked to pay larger and larger shares of the investment, until eventually the programs will be on a purely market footing. Another problem is that a number of constituencies will promote pet projects or programs that are socially attractive but economically dubious. Eventually, both problems will require new assessment tools that can help establish cost-effectiveness and ensure that costs are borne by the groups that actually receive the benefits. A number of seminar participants called for a new era of collaboration between utilities and regulators to work through the various obstacles that now retard cost-effective investment in energy efficiency on both sides of the meter.

Over time, as these institutional problems diminish, as the customer culture takes root in utilities, and as efficiency programs become genuine profit centers, utility profits are likely to become increasingly disconnected from commodity sales. "The move to decouple profit from sales has great potential," commented John Sawhill.

To some extent this decoupling is already happening in a few regions. John Rowe noted that, as a result of the shared-savings formula in New England, "energy conservation, at least in the short run, is the most profitable business I have." Ralph Cavanagh, staff attorney with the Natural Resources Defense Council, remarking on the progress in California with incentives for efficiency, said, "The most credible voice in the utility industry today in electrotechnologies is Southern California Edison, because SCE can say with absolute truth that its own shareholder profits are totally unaffected by how rapidly customers spin the meter."

New urgency

There was little question in anyone's mind that the nation's trial-and-error approach to realigning utility business with customer efficiency would eventually yield a workable solution, were it not for the new sense of urgency brought on by the global climate issue. Time and again the participants returned to the climate discussion, along with the largely unwelcome prospect of accelerating energy efficiency through market intervention or regulation as a means of curtailing carbon dioxide.

"I can't overstate the importance of CO_2 as an issue," said Ralph Cavanagh. "It looms above all other environmental consequences of electricity generation because it is the one totally unregulated pollutant. Costs associated with all other major pollutants have been incorporated in some fashion into the price of electricity."

As the discussion moved further out into the uncertain future, and as participants reacted to the notion of bringing future environmental costs back into the present through some type of price internalization—in the form of carbon taxes—the lines of advocacy became more apparent.

"CO_2 is beginning to crystallize as a future financial risk, and any long-term commitment to new generation sources that produce CO_2 must consider this financial exposure," said Cavanagh. "Utilities must begin to prudently anticipate some increases in the cost of emitting CO_2. Therefore, it is time to begin anticipating these external costs in utility planning, even if you disagree with the whole idea of CO_2 fees or taxes."

John Rowe argued against the idea of utilities including externalities in decision making. "These kinds of externalities are particularly pernicious environmental taxes. If you pick a number too high, you are stuck with it for a long time. I prefer taxes imposed directly, and I prefer them imposed across the board—on nonutility generators, industry, and foreign competitors, as well as ourselves."

Robert Bozzone, president and CEO of Allegheny Ludlum Corporation, captured the sentiment of the manufacturing community. "I get very concerned about a carbon tax being imposed on us through the utility base," he said. "I have a $50 million energy bill; add taxes on top for CO_2, and I have less capital to be competitive. I have 6000 employees I'm concerned about, and I'm facing a French-government-owned steel industry that is rapidly eating up the world."

Most participants made it clear that in their view the world is not yet ready for serious carbon taxes. Heads nodded when Gordon Hurlbert, president of GCH Management Services, said, "We should be careful. Carbon taxes will not only hurt the competitive position of U.S. industry but hurt the less-developed nations as well." Picking up on this point, Henry Linden, director of the Energy + Power Center at the Illinois Institute of Technology, remarked, "We are looking at high-efficiency coal-based systems, such as integrated gasification–combined-cycle systems, as the mainstay of the developing world—China, India, elsewhere."

Buying time

Ironically, the one element holding the participants together, helping them to retain a unity of purpose in debating the long-term energy future, was the efficiency resource itself. Everyone agreed that the newfound efficiency resource buys us time—providing us with enough precious breathing space to avoid the foreclosure of key energy options and to prevent certain paralyzing conflict over premature action, such as the imposition of large-scale carbon taxes.

"The size of the efficiency resource suggests that we don't have to determine today what the winners will be," said Ralph Cavanagh. "We have some time to experiment. And we may hope that what will emerge will be a fair, competitive process."

Chauncey Starr, EPRI president emeritus, added, "The climate issue suggests that we have a problem that will begin to raise its head in 20–30 years and become significant in 50 years. All the history of capital turnover says that a half century is the proper time scale for changing energy systems. Today we don't know what the competitive technical development of nonfossil sources is likely to be. We don't now know what value to put on CO_2 reduction, and we won't know for quite a while."

Arthur Rosenfeld believes that we should take advantage of this critical window, keeping all our options open and even strengthening the most promising options through R&D. "We have a while before the CO_2 threat is very serious—perhaps 20 years. And thankfully, we have five good irons in the fire to deal with CO_2 if and when it does become serious: nuclear, wind, photovoltaics, biomass, and the next generation of efficiency. I can't say which of these will look best in 10 or 15 or 20 years, but my guess is that when the dust settles in 20 years, the next generation of energy-efficient technology will probably still be the leader. Nevertheless, all five of these options deserve serious R&D programs today."

Rosenfeld's idea for a serious R&D program is about $500 million a year for each of the five programs—in total, $2.5 billion, roughly one-half of 1% of the U.S. energy bill. To support it he would propose a small CO_2 tax on a global basis. "The world is not ready for serious taxes on CO_2," he said, "but it might be prepared for a tiny tax, say on the order of 10¢ per ton. No one would notice it, but worldwide this would generate some $2 billion to $3 billion, which we could put into cooperative research."

Achieving international support for an incremental tax to fund R&D would be an unprecedented accomplishment. But no one in the room dismissed the notion, perhaps because it seemed to level the playing field for competitors on a global basis and perhaps because it offered a form of insurance against the great uncertainties of potential climate change.

Several participants attempted to transcend the discussion as to which particular energy option would or should prevail. Henry Linden, for one, believes that "we need to agree on an end point—a long-term, inexhaustible, sustainable energy system for a world population of 20 billion people. Then we can judge whether our concerted actions are moving us along this path to arrive at our end point within 50 to 100 years. My own position is that this end point should involve total electrification of

"The world is not ready for serious taxes on CO_2, but it might be prepared for a tiny tax, say on the order of 10¢ per ton. No one would notice it, but worldwide this would generate some $2 billion to $3 billion, which we could put into cooperative research."

ARTHUR ROSENFELD

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all stationary uses within 50 to 100 years, and high-energy-density chemical fuels for transportation—hydrogen comes to mind."

The electrification imperative

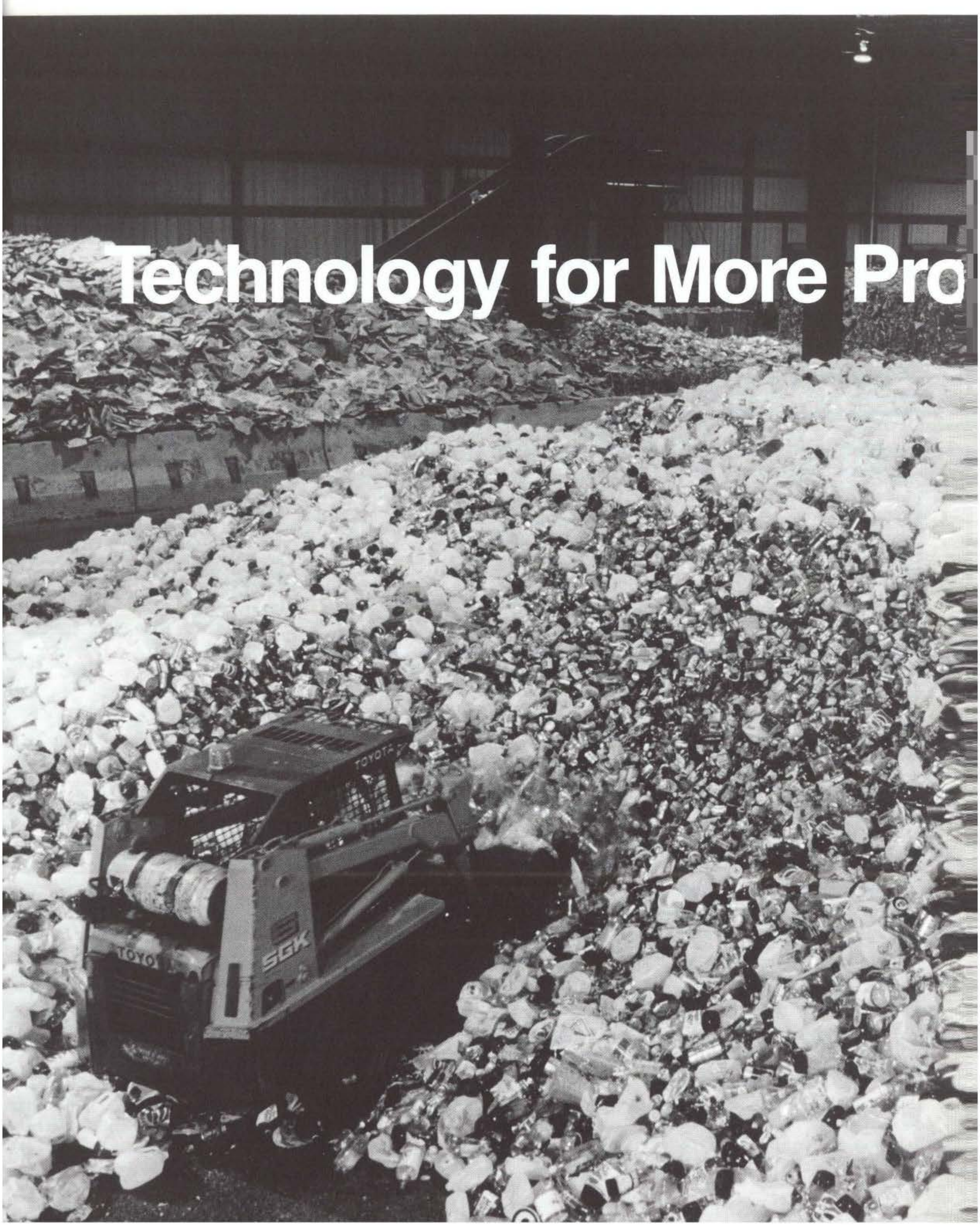
Chauncey Starr extended Linden's point about global sustainability, arguing that electrification will be a critical factor in curbing population growth in the developing nations.

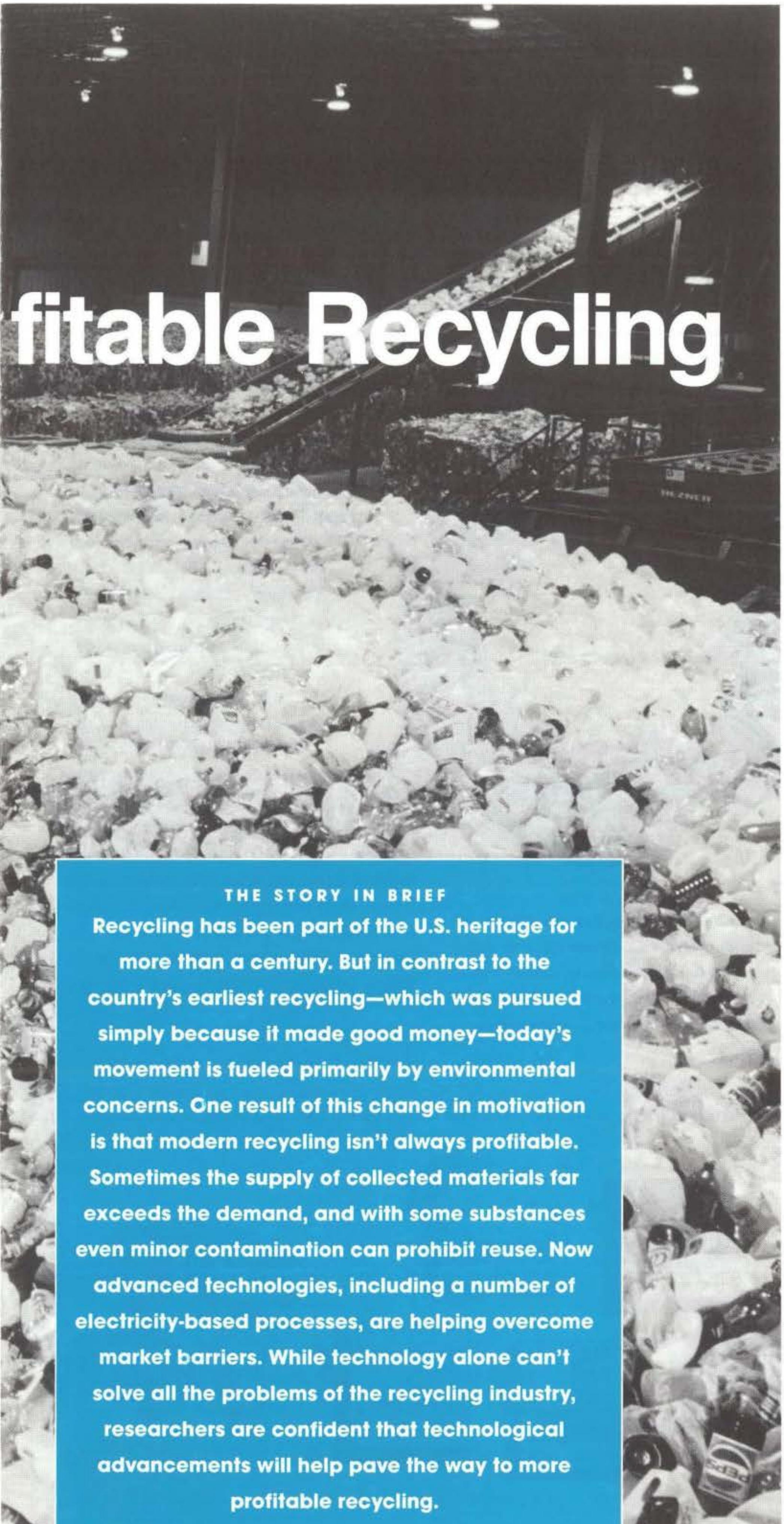
"Electrification is an economic imperative because electricity is the most efficient way to use the world's resources, including people, capital, and mineral and energy resources," said Starr. "It is the only way that production levels per capita can be raised in the developing nations—the only way to improve the scale of living for these populations so that they are sufficiently motivated to control the size of their families. Most demographers agree that when you raise income per capita, you get a self-induced population control." There is a certain irony to Starr's logic of using prosperity—with all its attendant material demands—as a strategy to bring the world's appetite for resources under control. Nevertheless, he contends that "there is plenty of historical and experimental evidence that prosperity helps to stabilize population.

"Any reasonable population projection you use leads to energy use in the twenty-first century that is multiples of today's use. We will be putting out CO_2 in much greater volumes, even if we do everything we can to push the maximum levels of renewable energy and conservation. Therefore what we really achieve is time—an intergenerational deferment but not a cure to global climate."

But with the world's population expected to reach 9–13 billion by the middle of the next century under the best of conditions, the global climate issue itself is likely to be subsumed by the larger issues of economic and environmental sustainability. "And it's in these areas that energy efficiency and electrification really shine," Starr pointed out. "If we can use these tools to ensure sustainability, we will have used the deferment window to the best possible advantage." ■

Technology for More Pro





fitable Recycling

THE STORY IN BRIEF

Recycling has been part of the U.S. heritage for more than a century. But in contrast to the country's earliest recycling—which was pursued simply because it made good money—today's movement is fueled primarily by environmental concerns. One result of this change in motivation is that modern recycling isn't always profitable. Sometimes the supply of collected materials far exceeds the demand, and with some substances even minor contamination can prohibit reuse. Now advanced technologies, including a number of electricity-based processes, are helping overcome market barriers. While technology alone can't solve all the problems of the recycling industry, researchers are confident that technological advancements will help pave the way to more profitable recycling.

WAY BACK IN THE EA DAYS, before recycling the "in" thing to do, tin dlers in horse-drawn wa traveled door-to-door in search of s metal. Ragmen journeyed far and wic collect used woolen and cotton cloth. was over a century ago, back when United States was resource-rich and before the emergence of the concept tha cycling is good for the public image. It a movement driven by basic economic mon sense—recycling made good mc

Today's much larger scale recy movement is motivated more by envi mental than economic concerns. Lar space is dwindling fast, and natura sources are no longer abundant. Muni programs that have emerged in recent y have succeeded in getting Americans i million homes to separate their trash. United States is now recycling all kinc materials—from plastics to batteries.

But there are problems with the sys Often the supply of given recyclables ceeds the demand for the materials. recycling facilities are not always equi to deal cost-effectively with even m contamination of a given waste strean addition, it is sometimes cost-prohibiti transport materials from urban areas, w they are generated, to recycling facilitie cated in rural areas.

To a certain extent, modern techno already at work behind the scenes is ing overcome some of these market riers. And more work is being condu to build on these accomplishments. searchers are exploring applications for technologies, including advanced ele technologies, that have the potential to prove the recycling process. The aim help recycling in this country once a make economic sense.

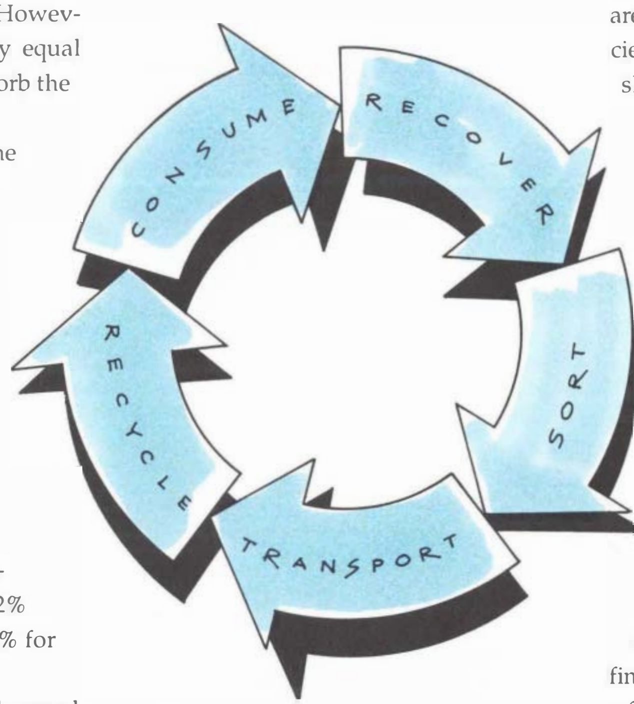
Today's garbage

Each year the United States generates than 11 billion tons of nonhazardous s waste, including industrial waste; w from the exploration, development, production of oil and gas; mining w and municipal solid waste (MSW). MSW includes many kinds of nonhazardous wastes that wind up in municipal landfills, such as waste from homes and commercial establishments and from some industrial sources. According to the U.S. Environmental Protection Agency, the United States recovered about 13% of its MSW for recycling in 1988, the most recent year for which figures are available. That's nearly double the 7% that was recovered in 1960. However, recovery does not automatically equal recycling. Markets must exist to absorb the collected materials.

As was true in the early days of the tin peddlers, iron and steel scrap are among the most widely recycled materials in the waste stream today. More than half of the ferrous metal produced by U.S. mills comes from recycled metal. Aluminum has a similarly strong record. About 64% of the more than 86 billion aluminum cans manufactured annually are recovered. The recovery of other materials has yet to catch up. Comparable figures are 33% for paper, 12% for glass containers, and less than 2% for plastics.

Today there are all kinds of advanced technologies available to improve the recycling process. And electricity plays an important role. "Electricity makes a major contribution as the dominant power source for the great variety of processing equipment involved in recycling," says Joe Goodwill, director of EPRI's Center for Materials Production (CMP) at Carnegie-Mellon University.

THE RECYCLING LOOP **Many believe that the success of recycling depends largely on how many people separate their trash for collection, but this step represents just the**

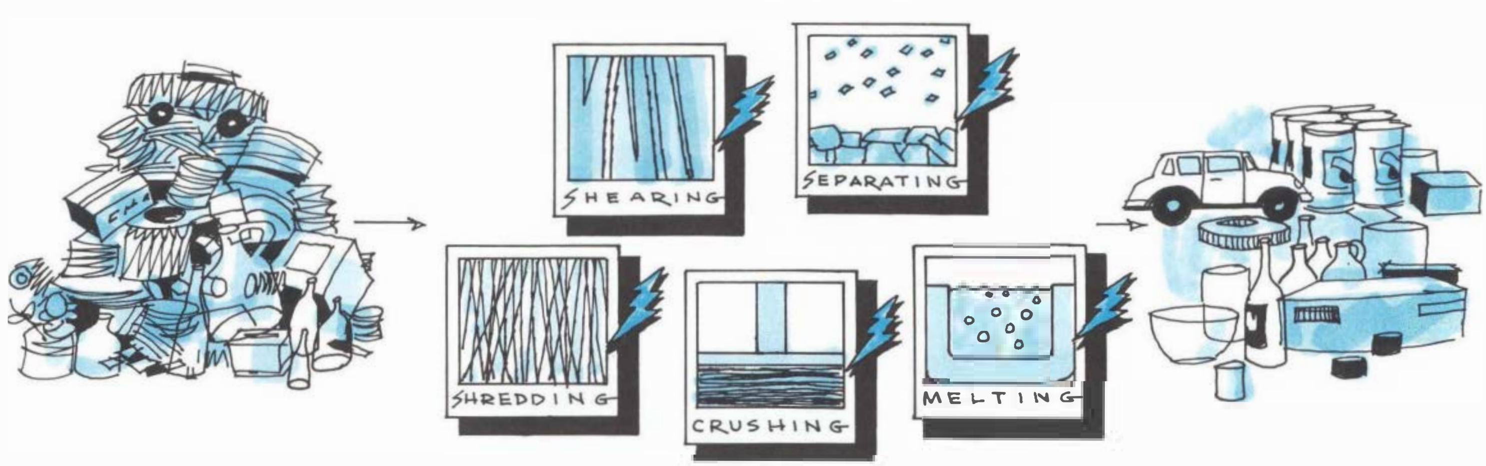


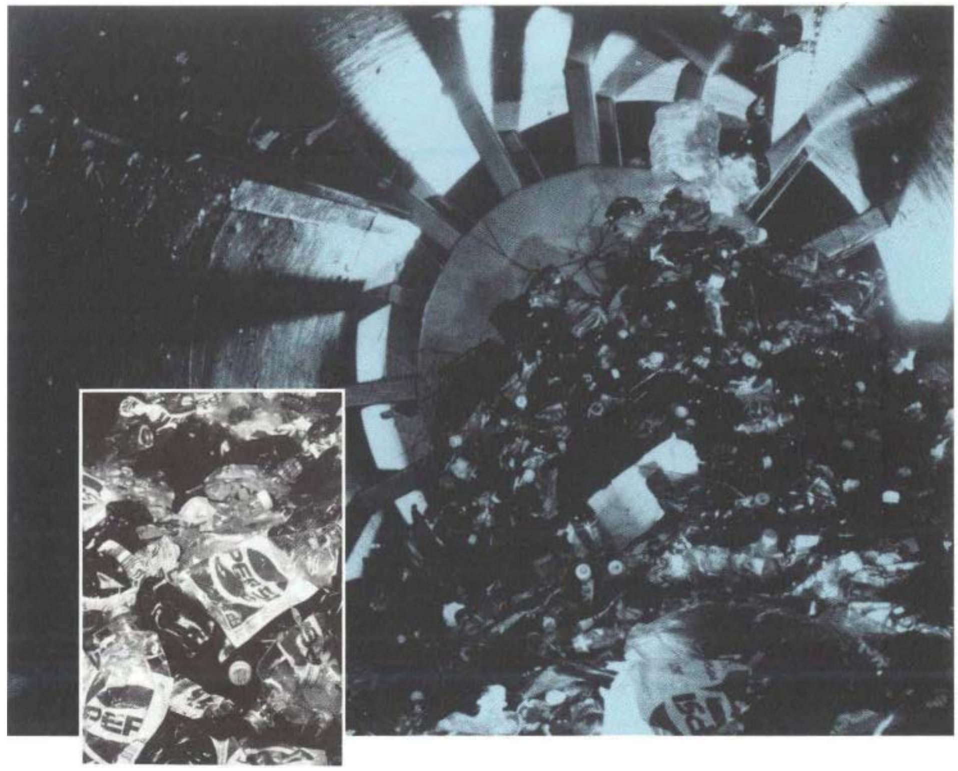
beginning of the long, complex process of transforming used materials into new products. Significant challenges involving human, technological, and market factors are encountered in each phase of the recycling loop.

The electrically powered equipment that helps prepare and process recyclable materials ranges from simple motors and conveyors to advanced electrotechnologies that are making the recycling process more efficient than ever before. Electrically powered shredders rip apart automobiles and appliances, reducing them to fist-sized pieces. Air separators blow pieces of foam away from the metal waste streams that result. Electromagnets remove steel rods from crumbled concrete. Electrically powered crushers shatter glass bottles into bite-size pieces. Giant blender-like agitators mash and mix old newspaper into a recyclable pulp. The list goes on.

On the processing side, several advanced electrotechnologies have already helped make recycling more efficient. For instance, the electric arc furnace can use 100% scrap metal to make finished steel, compared with 25% scrap for a fossil-fired oxygen furnace. A more recent technology is the plasma-fired cupola. The plasma cupola, a commercial product of EPRI's Industrial Program, allows for the

ELECTRICITY IN RECYCLING **Electricity plays an important role in the recycling of many materials and goods, from automobiles to soda bottles.**





use of smaller scrap, which typically would spew out the top of a conventional cupola. The plasma cupola can boost annual melting capacity by as much as 50%.

The electric arc furnace and the plasma-fired cupola are considerably more energy-efficient than their alternatives, mainly because in both cases, the electric energy is applied directly to the material and is not wasted on heating the furnace interior. "Electrotechnologies offer a distinct advantage, especially in processes that involve heating," says Pat McDonough, a project manager in EPRI's Customer Systems Division who oversees the CMP's activities. "The hotter you are heating something, the more efficient and environmentally sound—in terms of emissions levels—an electrotechnology will be. And electrotechnologies will always offer better control."

Glass action

A number of technological developments are under way to improve all kinds of recycling processes. Some of these involve the use of electricity. For instance, CMP is helping to fund a project that will test an optical device that removes ceramic from streams of crushed glass, called cullet. The project is funded primarily by the New York State Energy Research and Development Authority.

Ceramic contamination is one of the biggest problems plaguing the market for cullet today. Glass recyclers have turned away truckloads of glass that were found to contain even a small bit of ceramic. Typically, this glass winds up in a landfill, exactly where environment-conscious consumers least want to see it.

The ceramic comes in the form of broken coffee mugs and plates that well-intentioned consumers throw into their glass collections to be recycled. Ceramic will not melt in a furnace, as glass will. If any ceramic particles manage to slip through the recycling process, they emerge as stone-like objects embedded in the final glass product, which must be rejected.

Typically, ceramic is still sifted from the glass stream the old-fashioned way—by hand sorters. The optical device being demonstrated relies on infrared light to sense ceramics in the glass stream. Here's how it works: a stream of cullet, crushed into pieces less than 1 inch in diameter, travels along a conveyor and passes over a sheet of glass. Above the glass sheet is an infrared light source. Below it are detectors that can read this light.

Both the cullet and any paper label remnants clinging to it allow the light to pass through. But the ceramic pieces block the light. As a result, the detectors sense a shadow. This information is instantly sent to a central processor, which opens up a valve to release a quick blast of air. The air shoots the ceramic onto a second conveyor, which discards it. The glass loss, which occurs when chips of cullet are rejected along with the ceramic, is usually less than 2%. The infrared sorter is scheduled to be tried out at the Resource Recycling Technologies plant in Syracuse, New York, this spring.

CMP has also been exploring the potential of optical technologies for sorting glass by color. While such technologies are new to the U.S. glass-making process, they have been used in Germany for some time. They are also employed in the U.S. food-processing industry.

Don Klesser, a project consultant for CMP, says that optical technologies have the potential to improve the market for cullet. "There is no doubt in my mind that more cullet would be used if it were better sorted," he says, noting that U.S. glass recyclers use an average of 30% cullet in their recipe for recycled bottles. Raw materials like sand, limestone, and soda ash make up the remaining 70% of the mix. Because raw materials require more energy to process, an increase in cullet results in energy savings. According to Klesser, for every 10% increase in cullet, there is an energy reduction of 3%.

Successes and challenges

Even the most well developed recycling processes offer room for improvement. The recycling of aluminum is a good example. Aluminum recycling has been successful largely because making aluminum cans out of raw material takes about 16 times the energy needed to make them from used cans. To make aluminum from raw material, aluminum oxide must be extracted from bauxite. The extraction process requires so much energy that the power input for this application alone represents nearly 2% of the electricity consumed in the United States.

While recycling aluminum to make new products offers clear benefits, there are some challenges as well. A key concern has been the dross, or scum, that forms on the surface of the molten metal. In the case of

Recycling in Industry

EPRI has initiated several projects to explore the use of advanced electrotechnologies and electrical processes in industrial recycling. Here are a few examples.

Reverse osmosis

Food-processing plants are heavy users of water, with an average consumption of about 1 million gallons a day per plant. Typically, water used to wash vegetables and fruit and to preserve, pickle, or otherwise treat this food passes over the food only once. This year EPRI will initiate a project that aims to recover and reuse this water.

Together with Pacific Gas and Electric and local food-processing trade organizations, EPRI is investigating the use of a reverse osmosis unit that will run the used water through a membrane that retains materials—such as sodium and chloride—that contain ions. For instance, if a brine solution used for processing vegetables runs through the membrane, salt in the solution will be concentrated. The result is a stream of clean water, which can be reused, and salt, which can also be reused.

A variety of membranes will be tested during the EPRI study. Plastic membranes are expected to be the most common type used, but ceramic and sintered stainless steel are also expected to be tested. A trailer-mounted unit will be hooked up to existing systems at about 10 food-processing plants in California. National food-processing trade organizations are also involved in the project.

Advanced reverse osmosis

EPRI and Pacific Gas and Electric are funding a demonstration of an advanced reverse osmosis unit at a plant in Fremont, California, that makes disks for hard drives. The finely controlled process of plating the disks with nickel involves large quantities of deionized water, which is expensive to make. Typically, the water is used once and then disposed of.

The advanced reverse osmosis process differs from the conventional process in that microprocessor controls in the advanced procedure help optimize the operation of the plastic membranes used. The controls regulate the pattern of liquid flow through the membranes over time, ensuring consistent performance until the membranes are replaced at the end of their useful life.

The concept of replacing the membranes is also part of the advanced process. Previously, reverse osmosis was employed only in applications that would not damage the membranes, because they were expensive to replace. But the cost of the membranes has declined as they have become more widely used.

The membranes act as filters, screening out contaminants as water flows through. Two streams result from the process. One of them, representing about 95% of the initial stream, goes directly into the facility's deionized-water system, where it is prepared for reuse. The other, representing about 5% of the initial stream, must be treated further.

The contaminated stream contains nickel, which can be precipitated out. This results in two streams, one of which is pure enough to be disposed of through a sewer system. The other stream is a sludgelike precipitate that contains recoverable nickel.

RELATED WASTE MINIMIZATION/ TREATMENT PROJECTS

- Electron beam water disinfection
- Microwave water-oil separation
- Ozonation of drinking and cooling water
- Pyrolysis of medical waste
- Ozonation of pulp mill effluent
- Freeze concentration recovery of dairy whey

The Brayton-cycle heat pump

Under the sponsorship of the U.S. Department of Energy, the tape manufacturer 3M has modified existing Brayton-cycle heat pump technology for use in recovering volatile organic compounds (VOCs) from its manufacturing processes. VOCs, such as those present in the solvents that 3M uses to make its products, are harmful to the environment. Traditionally, industries have burned VOCs to prevent them from escaping into the atmosphere. But burning does not completely destroy VOCs.

As an alternative to this practice, 3M has employed the Brayton-cycle heat pump. The heat pump compresses solvent-laden air, then expands it. During the expansion process, the material chills and VOCs can be recovered as a liquid for reuse. The company, which owns the patent for this new technology, has designed a unit to recover about 90% of the VOCs that flow through it. The unit is installed at a 3M plant in Oklahoma.

EPRI, along with Southern California Edison, DOE, and NUCON International, which is licensed to manufacture 3M's technology, initiated a project to test the application of the Brayton-cycle heat pump for similar purposes in four manufacturing plants in the Los Angeles area. A trailer-mounted unit has already taken air samples from these operations and passed them through the heat pump to recover VOCs. The results to date indicate that the success of VOC recovery depends on the freezing point of the particular VOCs in use, among other factors. More-detailed results will follow. □

aluminum made from raw material, the dross is white and can be recycled through existing methods. In the case of used aluminum, however, a black dross is generated. The black dross is created by a number of contaminants that come with the old aluminum, such as paint coatings and metals like lead, brass, and zinc. Because old aluminum is paid for by the ton, some sellers have used these kinds of metals and other materials to make their loads heavier.

While black dross is not classified as hazardous, it cannot be reused, and typically it is hauled off-site or simply stored. EPRI is now developing a process to recycle the dross. The process involves the use of plasmas, or ionized gases, which can generate higher temperatures than a gas furnace can generate. The plasma process results in two streams, one containing pure aluminum, which can be sold, and the other consisting of waste. The waste stream is typically 30% smaller than the original waste stream. According to McDonough, the concept for the plasma process has been proved through a laboratory-scale plasma arc furnace. EPRI has applied for a patent on the process and plans to build a pilot unit.

Among the most challenging recycling processes today are processes for plastics. One difficulty is that there are many different types of plastic, each with different additives that call for slightly different recycling processes. At the same time, the cost of making plastic from raw materials is comparatively low—as much as 12¢ per pound cheaper than recycling. An added problem is that plastics get weaker when they are recycled. For this reason, the finished products typically contain only 10–25% recycled material.

A number of organizations are working to improve plastics-recycling processes. Among them is the Plastics Recycling Foundation. Based in Kennett Square, Pennsylvania, the foundation funds plastics-recycling research at several universities in the United States. One area of work funded by the foundation is the development of processes that use organic solvents to separate plastics at the molecular level. According to Wayne Pearson, executive director of the foundation, such processes permit the recycling of mixed plastics and, as a result, cut the cost of sorting. Another benefit is that a wider variety of plastics, including an assortment of plastic packaging currently being discarded, have the potential to be recycled. Molecular separation technology is not yet economically viable, but Pearson says that it will become more so as the process is refined. In the meantime, another process being developed involves the use of chemical additives that allow different plastics to be recycled together, resulting in a material just as strong as plastic produced from raw materials.

Paper chase

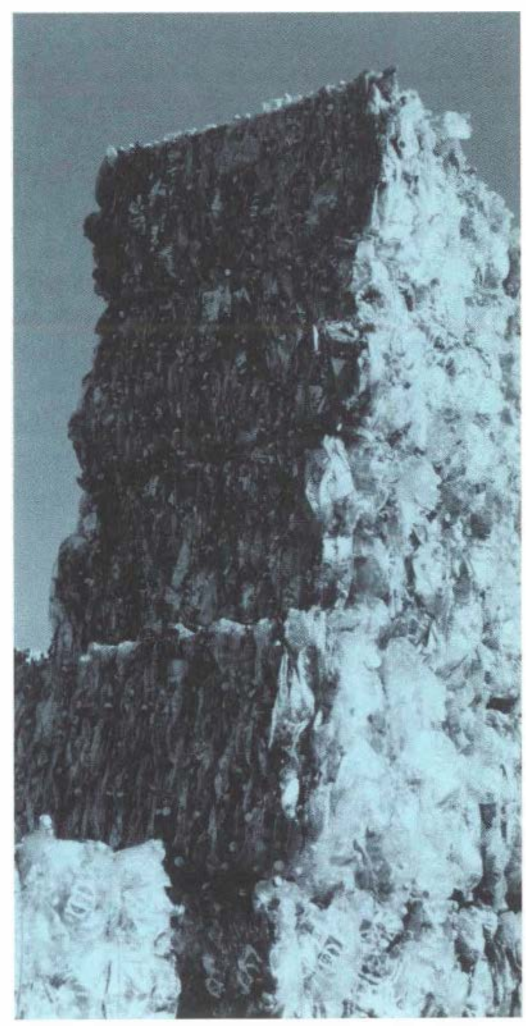
As is the case with plastic, different types of paper must be sorted before they are recycled. For instance, newsprint cannot be used to make high-quality writing paper. This is because newspaper contains lignin, the substance in wood that holds fibers together. Lignin is responsible for the yellowing effect that results when newsprint is exposed to sunlight.

Similarly, it has been necessary to separate glossy magazines from newspapers because removing the clay used to create the gloss requires an extra step, which also increases the expense of the process. One relatively new technology has helped overcome this problem, however. Known as the flotation process, this technology has been used in Europe and Japan but is just now beginning to come to the United States.

Flotation systems are an alternative to the traditional washing machinery used to remove ink in the recycling process. In traditional washers, a surfactant removes ink particles from the paper, and the particles are washed away by water. In flotation systems, the surfactant generates a foam that carries the ink to a flotation chamber, where it can be skimmed off. One side benefit is that old magazines actually help speed up the de-inking process. Clay particles removed by the surfactant help trap the ink inside the foam. Recyclers have found that a mixture of 30% old magazines and 70% old newspapers yields the best results.

Ammi Amarnath, a project manager in EPRI's Customer Systems Division, notes that flotation systems have, in effect, improved the market for old magazines, which have been considered difficult to recycle. "This is a perfect example of how advanced technologies can help overcome the kind of market barriers that exist to wider-scale recycling," Amarnath says. "In effect, technologies can be a shortcut solution to these kinds of market problems." Improved technology, he notes, may well help the U.S. paper industry toward its goal of a 40% recovery rate by the end of 1995.

EPRI's Pulp and Paper Office, which Amarnath oversees, is now involved in a study that will identify possible new applications for advanced electrotechnologies in the paper-recycling process. Results are expected sometime during the second quarter of this year. Bob Hart, manager of the office, expects the heat pump to be one candidate produced by the study. Already, heat



pumps have been used in the paper industry for capturing otherwise rejected steam and using it to dry paper.

Hart believes that, used in a similar fashion, heat pumps may also enhance a new process for recycling that uses steam. This process, called steam explosion, is expected to decrease significantly the cost of recycling paper.

In the steam explosion process, waste paper is put into a chamber under high pressure. When the paper is released from the pressure, it literally explodes. The explosion dissipates the ink and breaks the glue bonds that hold the paper together. Stake Technology Ltd. and Chesapeake Corporation, a paper maker in Richmond, Virginia, have joined forces to market the technology for use with all kinds of paper. Plans are to install a pilot unit by April of this year. A demonstration will follow.

One barrier to increased paper recycling that can't be solved with a process technology is the issue of transportation. The problem is that the bulk of used newsprint and other waste paper is generated in urban areas, while the mills with recycling facilities generally are located in rural regions. Transporting the paper to the remotely located mills is sometimes cost-prohibitive. In fact, sellers who once got $40 per ton for old newspapers have actually had to pay buyers to haul the stuff away.

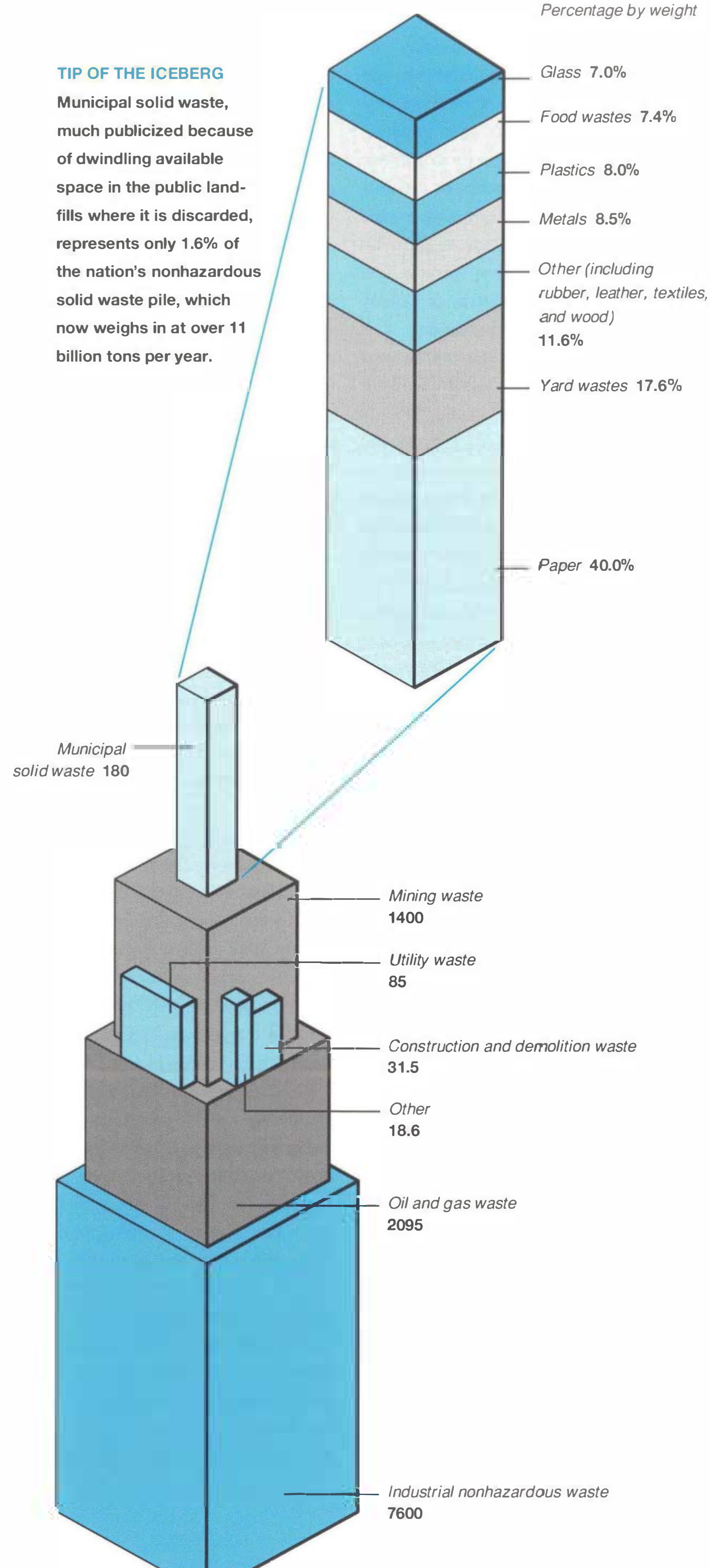
"There is no technological solution to this problem, short of building recycling centers closer to the urban areas," Amarnath says. He points out, however, that there has already been some movement in this direction. For example, Champion International, a paper company, is building a facility in the Houston area specifically to process the glut of old newspapers that is now clogging the market in that area.

The big waste stream

Much media and government attention has been focused on municipal solid waste. But MSW accounts for only about 1.6% of the 11 billion tons of nonhazardous solid waste generated by the United States each year. Tracking the remaining waste, the bulk of

TIP OF THE ICEBERG

Municipal solid waste, much publicized because of dwindling available space in the public landfills where it is discarded, represents only 1.6% of the nation's nonhazardous solid waste pile, which now weighs in at over 11 billion tons per year.



Based on EPA data from 1970-1988, in millions of tons which is disposed of in private landfills, is a more difficult task.

By far the biggest single portion of this waste pile—about 69%—is generated by industry. Other large components are oil and gas waste and mining waste. It is in the industrial area that EPRI has focused its main recycling efforts. The Institute has initiated a number of projects to help improve the recycling of a variety of industrial wastes.

These projects, which range from recycling and reusing volatile organic compounds in the high-tech industry to recycling wastewater in the food-processing industry, take advantage of specific advanced electrotechnologies in the recycling process. Not only do the firms involved save on dumping and sewer fees, but they earn the benefit of reusing the recycled product. (The sidebar highlights some of EPRI's projects in the industrial sector.)

"On-site recycling in the industrial sector is probably the best kind of recycling there is, because you don't have to deal with issues of collection, transportation, and supply and demand," says Amarnath. "These are the kinds of issues that make the recycling of MSW so challenging."

Many of the projects in the industrial sector were initiated primarily for economic reasons. For instance, a sand-recycling project was propelled by a need in the nation's foundries. U.S. foundries, which annually use 7 million tons of sand for molds to make cast-metal parts, pay about $20 per ton for the sand. Yet it typically costs about $30 per ton to dispose of the sand after it is used.

EPRI's ongoing project involves the development of two sand reclaimer technologies—one involving electric infrared technology, the other electric resistance. The reclaimers burn off the chemical and clay binders that hold the used sand together. The result is clean sand, which can be reused by the foundry. As McDonough points out, "If we can get more foundries to recycle their sand, they may be more competitive in a global market." (For more information on this project, see "Electrifying the Foundry Fire," *EPRI Journal*, October/November 1991, p. 16.)

Another advantage of recycling in the industrial sector is that in some cases, the process also addresses the issue of hazardous waste. For instance, a past EPRI project involved recycling the dust generated by electric arc furnaces used in steel melting. The dust is considered hazardous because it contains materials like lead and zinc. The EPRI project demonstrated the application of a plasma arc reactor to recycle this material. The plasma process vaporizes the zinc, which then condenses into its metallic state. Zinc has a relatively high value and can be sold for about 45¢ or more per pound. As a result of this EPRI project, the plasma process was installed to recycle electric arc furnace dust in two U.S. steel plants. "We expect that this technology will be adopted by other steelmakers now that it has been shown to be cost-effective," McDonough says.

A long haul

Though these projects in the industrial sector and other technological innovations in the MSW area promise to facilitate recycling, getting the technology adopted can be a long-term project in itself. Often it requires companies to make a major investment. Edgar Miller, program coordinator of the Recycling Advisory Council (RAC) established by the National Recycling Coalition to provide national leadership on recycling issues, points out that industries—particularly in a recessionary economy like today's—are reluctant to make large investments in new machinery.

"Right now, because of the impact of the poor economy and a decline in consumer purchasing, some of the facilities that make plastic bottles, paper, and other goods are experiencing an overcapacity in their existing machinery for producing these products from virgin materials," Miller says. "The last thing they want to do is go out and buy more machinery for recycling."

At the moment, there are not a lot of market incentives to invest in advanced technology. But there are other types of incentives. Among the flurry of state recycling laws and programs that have emerged in recent years are tax exemptions, grants, and loans for manufacturers who invest in recycling equipment. To date, at least 17 states offer such incentives.

While there currently are no such incentives offered by the federal government, the RAC is investigating a wide range of economic incentives and expects to recommend to the federal government the adoption of such incentives. Already the council has recommended that tax-exempt financing be made available to recycling organizations, both public and private, for investment in equipment and facilities. "The up-front money required to get into recycling is a real barrier. Some economic incentive is needed to help ease the transition for manufacturers," Miller says.

But Miller cautions that it is important not to focus on technologies alone. "We can't rely solely on a technological fix to address a problem that essentially runs through the entire recycling loop," he says. "Technological processes are just one part of that loop." Other parts, such as the collection and sorting infrastructure, also need attention, he says.

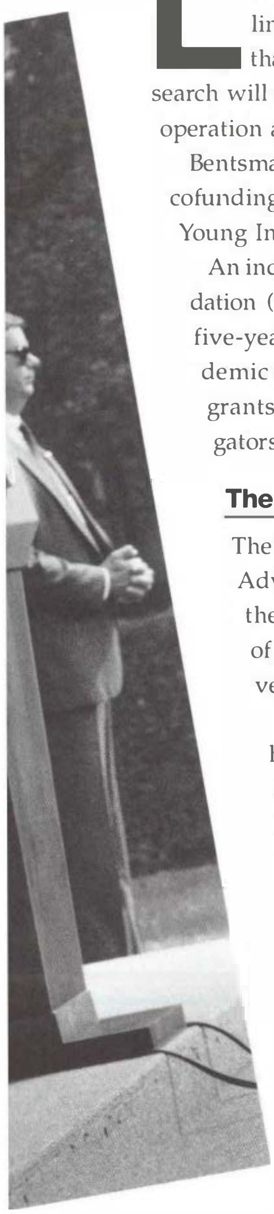
Given the scope of this issue and the magnitude of the mounting U.S. garbage pile, there is still much more work to be done, Miller acknowledges. In fact, the EPA aims to nearly double the current recovery of MSW to 25%. When one steps back from the MSW pile to see that it is virtually a molehill on the mountain of solid waste generated by this country, the view can be daunting. Nevertheless, Miller stresses, this perspective is important. "We've got to develop a big-picture view. One has to keep in mind that this is only the tip of the iceberg—or the tip of the mountain, in this case. We have just begun the fight." ■

Photos courtesy of Wellman, Inc.

This article was written by Leslie Lamarre. Background information was provided by Bob Jeffress, Pat McDonough, and Ammi Amarnath, Customer Systems Division.

Young Investigators Leverag

Research Power



LAST MAY, ASSOCIATE PROFESSOR JOSEPH BENTSMAN felt a rush of exhilaration. He'd figured out how to prove the stability of a class of nonlinear digital controllers. This may not mean much to most people, but that doesn't bother Bentsman or his adviser at EPRI, Sid Bhatt. "Joe's research will help in the development of intelligent controls to improve power plant operation and decrease the likelihood of accidents," Bhatt explains.

Bentsman is one of 13 outstanding university researchers whose work EPRI is cofunding in conjunction with the National Science Foundation's Presidential Young Investigator (PYI) Awards program.

An independent agency of the federal government, the National Science Foundation (NSF) was established in 1950 to spur progress in scientific research. The five-year PYI awards represent just one type of grant the NSF offers for academic research in the sciences, mathematics, and engineering. Of some 19,000 grants that the NSF awarded in 1991, 220 went to Presidential Young Investigators.

The PYI program

The PYI program was created in 1984, two years after Presidential Science Adviser George A. Keyworth II voiced his alarm to President Reagan that the nation's brightest minds were deserting academia for the higher pay of industry. PYIs have represented the crème de la crème of young university researchers ever since.

Each candidate must be nominated by his or her university department head or analogous administrative official. In selecting its winners, the NSF looks for several strengths. To start with, research and teaching competence must be demonstrated through published articles and letters of recommendation. But beyond these requirements, the NSF seeks candidates whose research will lead to practical applications of national significance and who are likely to become leaders in their fields.

Winners of the awards receive a base grant from the NSF of $25,000 per year for research, provided that their universities guarantee their salaries over the course of the five-year grant. On top of this sum, the foundation will offer up to $37,500 more per year, depending on how much in one-to-one matching funds (or the equivalent in equipment) the winner gets from industry or nonprofit organizations like EPRI. In short, PYIs like Bentsman can receive up to $500,000 for research support over five years. This money goes toward such expenses as the salaries of research assistants and the equipment related to the investigator's project. Some of the money (the equivalent of up to two-ninths of a PYI's academic year salary) can also be used to pay the summer salary of the PYI.

The grants are awarded with four goals in mind, the most important of which is to keep researchers in the academic world. The program's other three goals are to give the winners' research and teaching careers a financial boost, to improve the host universities' research capabilities, and to build bonds between academia and industry. While there is no

THE STORY IN BRIEF

EPRI has mounted a campaign to take full advantage of a valuable resource for utilities: the country's very best university researchers, as identified by the National Science Foundation. Through the NSF's Presidential Young Investigator (PYI) Awards program, the Institute now cofunds more than a dozen top researchers across the country. In this way, EPRI not only can leverage its research investment but also can direct entire projects toward specific problems or issues of importance to the electric utility industry. The result is top-quality, highly focused R&D that encourages the brightest minds in the university sphere to become and remain involved in utility concerns. Despite some organizational changes in the program, EPRI intends to continue its involvement in the coming years.

age requirement for eligibility, the program is restricted to those who are no more than six years beyond receiving their PhDs.

Competition for PYI funds is stiff. From 1984 through 1991, only 13% of the program's nominees received awards. Engineering winners top the list with 591 grants, followed by mathematics and physical sciences with 411 grants, computer and information science with 213 grants, biological, behavioral, and social sciences with 197 grants, and geosciences with 65 grants.

"Given that this award offers both prestige and substantial financial support, universities compete with each other to get as many PYIs as they can," says Mary Sladek of the NSF, manager of the PYI program.

In 1991, 38 universities boasted two or more PYI awardees. The Massachusetts Institute of Technology led with 11, followed by the University of Wisconsin at Madison with 10, Ohio State University with 9, Harvard University with 8, and the University of California at Berkeley with 7.

Both for-profit companies and nonprofit groups like EPRI have good incentive for participating in the PYI program. A relatively modest contribution can gain a cofunder the ability to steer the course of a PYI's research toward problems and issues of its industry. As Thomas R. Schneider of EPRI points out, much of the best research in the United States originates in universities. "We're recruiting the best minds in the country to work on problems of importance to electric utilities and their customers," says Schneider. An executive scientist in the Office of Exploratory and Applied Research, Schneider has initiated an effort to tap the PYI resource for the benefit of all of EPRI's technical divisions. "Our hope is that, by working with PYIs early in their careers on issues of importance to the industry, we will encourage them to continue to solve these problems throughout their working lives."

Schneider points out that the program also saves EPRI a lot of legwork in identifying top-notch researchers, because in selecting its PYIs the NSF has accomplished this task. Among other benefits of participating in the program, EPRI's name becomes more widely recognized within the university community, and problems of the electric utility industry are given more exposure among young scientists.

Other organizations also recognize the opportunity offered by the PYI program. Among the companies that have cofunded PYIs are American Telephone & Telegraph, General Electric, General Motors, Hewlett-Packard, IBM, Sun Microsystems, and Westinghouse. In addition to EPRI, nonprofit cofunders include the American Chemical Society, the American Gas Association, the American Electronics Association, the Gas Research Institute, the Lighting Research Institute, and the Petroleum Research Fund.

EPRI's involvement

Up until about two years ago, divisions within EPRI individually cofunded an occasional PYI, but there was no systematic, Institute-wide effort under way to take full advantage of this resource. Schneider recognized the great value PYIs could bring to EPRI while he was on loan to the Lighting Research Institute, serving as the organization's president from 1985 to 1987. Two researchers funded by that institute at the time were named PYIs, and their work eventually led to an entirely new science involving the use of bright light to treat winter depression.

Schneider returned to EPRI eager to increase the Institute's participation in the PYI program. With the help of Jack Hollander, professor emeritus of energy and resources at the University of California at Berkeley and a regular consultant to EPRI's Office of Exploratory and Applied Research, Schneider conducted a thorough investigation into the PYI program and discovered that a number of projects over the course of the program's history were applicable to EPRI's work.

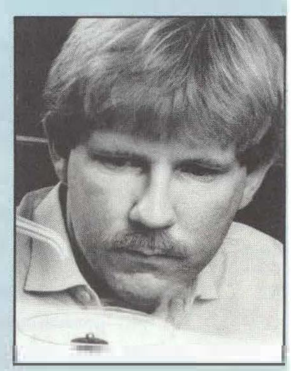
By 1990 Schneider was ready to mount a campaign to woo PYIs en masse. Together, he and Hollander screened that year's crop of 211 PYIs down to 31 whose work was closely related to the generation, delivery, or use of electricity. Schneider wrote to

WIDE RANGE OF

JAMES MOMOH, right, reviews a computer program with students in the Energy Systems Network Laboratory at Howard University.

JOHN BOOSKE, left, works with an undergraduate to find new applications for microwave radiation.

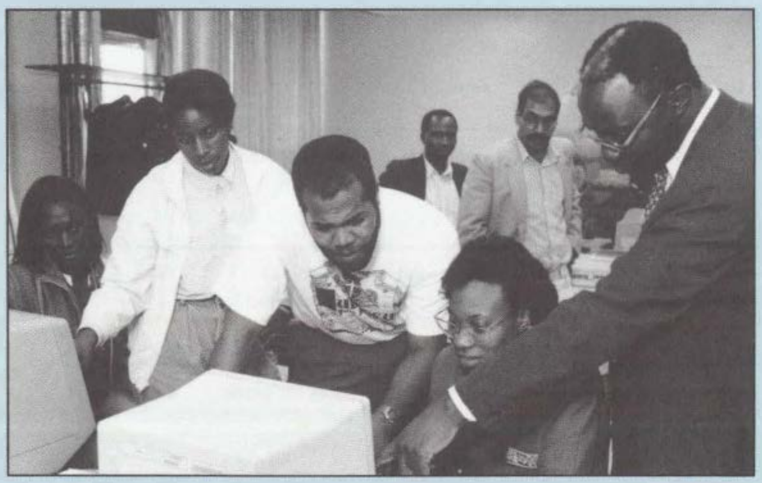
Photo by Bruce Fritz



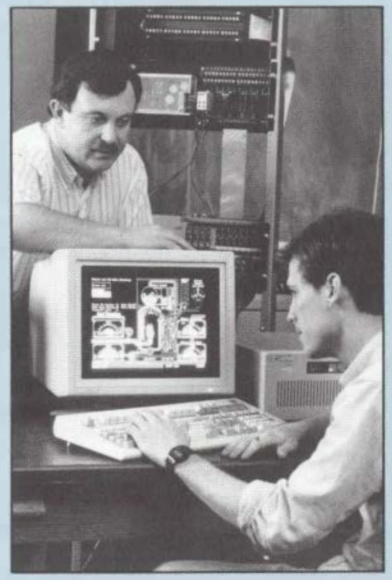
JOHN McDEVITT illustrates the magnetic levitation effects of superconductors.

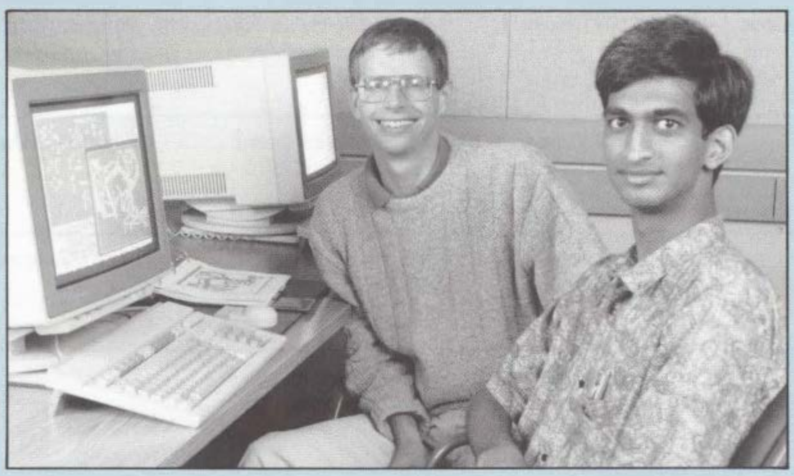
Photo by Larry Murphy

RESEARCH **PYIs cofunded by EPRI are working on a number of utility issues, from voltage collapse to solid-particle erosion.**

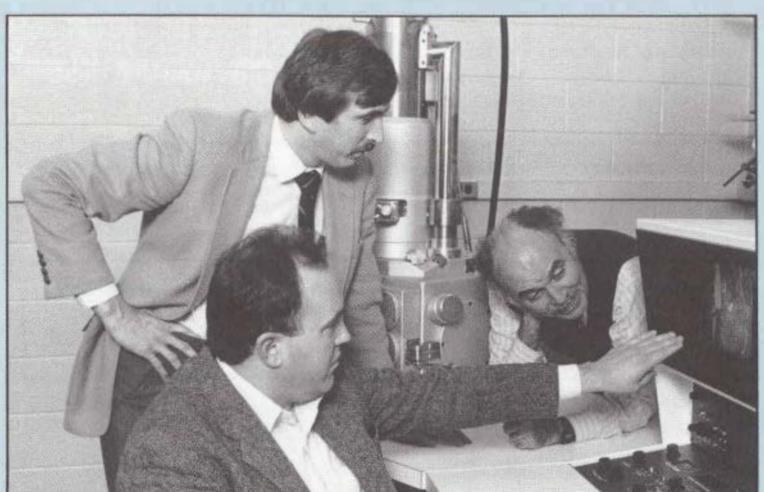


JOSEPH BENTSMAN, standing, assists a graduate student in modeling a boiler control system.





RICHARD CHRISTIE, left, works with a student to develop advanced computer representations of power system data.



JOHN HACK, standing, and two colleagues explore microstructures at Yale University's microdiffraction facility.

Photo by Michael Marsland

those 31 PYIs, and 20 of them responded. Of these 20, the Exploratory Research executive staff selected 7 for EPRI cofunding. Several others are still being evaluated.

In the meantime, 1991's crop of 220 PYIs has yielded 23 candidates for EPRI cofunding. Schneider has written to each of them, alerting them to EPRI's interest in their research, and is awaiting their responses. It is unlikely that all will be funded, however. The research interests of some of the candidates may prove to be insufficiently close to the interests and priorities of EPRI and its member utilities to qualify for support from the Institute. Also, in order to receive the Institute's money, the PYI must come to an agreement with EPRI on what research will be conducted and what direction the work will take.

Schneider's role in recruiting PYIs does not stop with the initial solicitation. He also finds technical advisers at EPRI for the cofunded PYIs and tracks their research progress. Typically, EPRI contributes between $15,000 and $37,500 per year to a PYI's project. As of November 1991, 13 PYIs are putting EPRI funds to work. Here are some examples of what they are up to:

▫ At the University of Wisconsin, John Booske is seeking to understand why microwave ovens allow ceramics to sinter at relatively low temperatures. Microwave ovens could save money in the production of ceramics used for widely different applications, ranging from insulators to fuel cell components.

▫ At the University of Washington, Richard Christie is looking at advanced ways to display information on computer screens to help power system operators more readily pinpoint and solve transmission problems.

▫ At the University of Texas, John McDevitt is developing superconductor-based optical detectors, which can be used to convert light signals into electrical signals for communication over the optical fibers that some utilities are now substituting for copper wires.

▫ At the University of Southern California, Eckart Meiburg is showing that new formulas can predict when efficiency-imped-

EPRI's PYIs

As of late 1991, EPRI was cofunding the 13 Presidential Young Investigators (PYIs) listed below. At least two dozen others are being evaluated for possible cofunding.

PYI	University	Area of Work	EPRI Adviser
Joseph Bentsman	University of Illinois	Controller synthesis for nuclear and fossil plants	Sid Bhatt
John Booske	University of Wisconsin at Madison	Microwave sintering of ceramics for insulators and fuel cells	Wate Bakker
Richard Christie	University of Washington	Advanced interfaces for power system operations	Gerry Cauley
John E. Hack	Yale University	Microstructural features of metals for improved resistance to fractures	Vis Viswanathan
Mohamad H. Hassoun	Wayne State University	Unit commitment scheduling in electric power systems	Rambabu Adapa
Doreen Leopold	University of Minnesota at Minneapolis–St. Paul	Metal clusters for faster, cleaner catalysts	Fritz Kalhammer
John Lienhard V	Massachusetts Institute of Technology	Motion of airborne particles for improved pollution control	John Maulbetsch
Chen-Ching Liu	University of Washington	Expert systems for power system operations	Gerry Cauley
John McDevitt	University of Texas at Austin	Superconductor-based optical detectors	Terry Peterson
Eckart Meiburg	University of Southern California	Solid-particle erosion in gas and steam turbines	John Maulbetsch
James Momoh	Howard University	Expert systems for voltage collapse; optimal power flow	Rambabu Adapa
Bahram Nassersharif	University of Nevada	Computer-aided design of power systems	Robert Colley
Vijay Vittal	Iowa State University of Science and Technology	Power system stability; dynamic security assessment	Rambabu Adapa

ing particle turbulence will occur in fluids flowing through gas and steam turbines. Ultimately his work could help designers of new equipment minimize the problem.

- At Howard University, James Momoh is developing an expert system to detect and prevent voltage collapse. He is also developing advanced algorithms to improve power flow. The algorithms will be incorporated into a software package to be used in the planning and operation of power systems.
- At the Massachusetts Institute of Technology, John Lienhard V is studying the way airborne particles are carried by the flow of gases in an effort to gather information for more-effective particulate control technologies.

Metals, molecules, and more

As Schneider explains, most PYI projects fall into two categories of research funded by his office: projects aimed at solutions to key problems and projects that explore a new area of science. But there is a third category of research that is less common: the pursuit of high-risk projects with potentially high payoff. This type of research may involve new phenomena or use innovative methods to solve existing problems. PYI Doreen Leopold's work falls into this category.

An assistant professor of chemistry at the University of Minnesota, Leopold and the six researchers she oversees are studying the bonding of chemicals to metals at the molecular level. Understanding the chemistry of these interactions could lead to faster, cleaner catalysts. That's because many of the catalysts that speed up chemical reactions in industrial processes involve the use of metallic compounds.

Fast, clean, and—especially—lower-cost catalysts could be quite useful to the utility industry. Catalysts are key to the economic magic worked by fuel cells, a relatively new technology that offers electricity from fuels without combustion. Improved catalysts also could increase the efficiency of the process that removes nitrogen oxides from the exhaust gas leaving power plant stacks.

"We call ourselves the APES group," Leopold laughs. The acronym stands for anion (negative ion) photoelectron spectrometer, a laser-based tool the group took three years to build. According to Leopold, this instrument, which probes the chemical bonding of atoms and molecules in metals, is one of only a few of its kind in the world.

EPRI's contribution to Leopold's project will help pay for graduate student research assistance for one academic year. Leopold also obtained cofunding from Allied Signal, Amoco, Cray Computer, Ford Motor Company, General Electric, IBM, and others.

Other PYI projects, such as Joe Bentsman's, are of more immediate application, directly addressing issues specific to the electric utility industry. An associate professor in the Department of Mechanical and Industrial Engineering at the University of Illinois at Urbana-Champaign, Bentsman teaches and researches control systems.

With a colleague, Bentsman leads a team of eight graduate students in the development of intelligent automatic controls for nuclear and fossil-fired power plants. When a plant's computers sense trouble brewing, he wants them to be able to identify the appropriate corrective actions so that the plant operates safely. He wants them to know the choices available, to know which choice to suggest, and to test that choice to ensure—before action is taken—that it is correct. As Bentsman puts it, "Control failure can result in loss of life, multimillion-dollar property loss, and damage to the environment."

"Joe's a great teacher, and his publication history is fantastic," says Bert Marsh, Bentsman's former NSF sponsor. "He's a key producer in the world of controls theory. But where he really stars is in asking questions like, 'Wait a minute, how do we make use of this in the real world?'"

As a technical adviser, Sid Bhatt of EPRI's Nuclear Power Division has helped Bentsman focus on ideas for intelligent controls specific to electric utilities—controls that will help the operators address malfunctions when they occur, maximizing the speed and accuracy of solutions. Bhatt also was responsible for drawing up the contract that provides Bentsman with enough money from EPRI to pay for research assistance and part of Bentsman's salary for three years.

Program changes

Over the course of the PYI program's eight-year history, three significant changes have occurred. Two of them came in 1985: behavioral and social science research projects became eligible for grants, and nonprofit organizations like EPRI became eligible as cofunders. Recently, the third major change was initiated.

Beginning this year, the program is being called the NYI (National Science Foundation Young Investigator) Awards program. While the size and duration of the grants and matching funds available from the NSF remain unchanged, fewer awards will be handed out. The NYI program calls for a maximum of 150 awards per year.

Concurrent with these modifications is the creation of a Presidential Faculty Fellows (PFF) program, also sponsored by the NSF. Announced by President Bush during a September 1991 Rose Garden ceremony honoring the nation's top scientists and engineers, this program provides up to 30 annual winners with $100,000 per year for five years. Matching grants are not part of the program, but winners are free to seek additional funds from industry or nonprofit groups.

Schneider says these changes should not affect EPRI's participation. "We'll persevere to engage these young people—PYIs or NYIs or whatever they're called at the time," he says. "The net result is that electric utilities and their customers benefit from top-notch work conducted by some of our country's brightest young researchers. I'd say that's a partnership well worth encouraging." ■

This article was written by Michael Scofield, science writer. Background information was provided by Tom Schneider, Office of Exploratory and Applied Research, and Sid Bhatt, Nuclear Power Division.

AT THE INSTITUTE

Strategic Plan Put Into Action

EPRI has adopted a new strategic plan that is intended to help make the Institute more readily responsive to the changing needs of its member utilities. A significant departure from previous plans, the 1992 Research and Development Plan is just one element of a major program under way to reposition the Institute to become more market-driven. The new plan offers a much more flexible and businesslike planning approach.

One fundamental change is that major industry issues, rather than research areas, serve as the plan's foundation. Established by the Institute's advisers, these issues are as follows: enhancing the value of electricity services, promoting environmental health, welfare, and safety, ensuring a sustainable electric future, and controlling utility costs.

By focusing on key industry issues, EPRI can help members prepare for increasingly competitive business conditions, anticipate and address emerging environmental concerns, take a more holistic approach to resource utilization, and improve the productivity of their current assets.

EPRI's Research Advisory Committee has established strategic objectives corresponding to each of the four industry issues. Together the issues and objectives will guide the management of EPRI's R&D program, keeping the Institute's research in line with members' needs. Measurable targets have been identified to satisfy each objective.

With explicit objectives and measurable targets, EPRI's advisers can more readily establish priorities in order to make the best use of available R&D resources. Another benefit is that quantifiable targets and milestones provide both utility advisers and EPRI management with clear yardsticks against which to measure R&D progress; the result is a system of accountability for meeting specific R&D goals.

The 1992 strategic plan is a direct result of a revised planning and management process, initiated after a major review of the Institute's corporate operations. In this review, EPRI asked top utility management how the Institute could deliver members more value for their R&D investment. Their response was for EPRI to become more businesslike, more market-driven, and better able to respond readily to changing utility needs.

Among the other initiatives resulting from the corporate operations review are the International Affiliates Program, through which utilities in other countries can participate in EPRI, and tailored collaboration, through which members can target extra research dollars toward special projects and receive matching funds from EPRI for those projects.

To order a copy of the 1992 Research and Development Plan, contact EPRI Corporate Communications at (415) 934-4212. ■

EPRI Consolidates Environmental R&D

To facilitate better coordination of its environmental R&D, the Institute has integrated key groups for environmental science and engineering under its Environment Division. Effective January 1, the Environmental Control Systems Department, formerly part of EPRI's Generation and Storage Division, joins the Environmental Sciences group under the direction of Environment Division vice president George Hidy. "Working together, these two groups can deliver more integrated, comprehensive environmental R&D," says Hidy.

A number of EPRI's environmental projects require the expertise of both scientists and engineers. For instance, engineers investigating chemical pollutants depend on risk assessments, performed by scientists, in order to rank the pollutants from the perspective of health and ecological risk. The engineers focus on collecting pollution data, defining and quantifying the pollutants emitted by a given system, and determining how well available technologies can control these emissions. The scientists determine which pollutants are most important for the industry to focus on, given the risks associated with each, and which plant designs are the most vulnerable to emitting toxic air pollutants.

In the new organization, Environmental Sciences director Stephen Peck continues to oversee the staff of 35 that conducts atmospheric research, ecological studies, studies of the health effects of electric and magnetic fields, environmental health studies, environmental risk analysis, and land and water quality studies. Joining that staff in the Environment Division is the Environmental Control Systems Department, headed by Ian Torrens. This group of some 30 staff members is responsible for programs that provide technologies and information for cost-effective air, waste, and water management.

"The Institute's commitment to providing environmental risk assessment and management tools is significant," says Hidy, noting that EPRI has the largest nongovernment environmental research program in the United States. This year EPRI's Environment Division will manage a research budget of about $100 million. ■

Washington Office Gets New Vice President

Robert L. Hirsch was appointed vice president for EPRI's Washington, D.C., office late last year. He has 30 years of experience in energy research, technology development, and energy policy.

Aside from directing the Washington office, Hirsch will serve as liaison to a number of groups in the capital area, representing EPRI with federal agencies, trade associations, and national scientific, academic, technical, and environmental organizations. His role will help ensure that the latest information on EPRI's research and insights is readily accessible. Hirsch reports directly to Richard E. Balzhiser, EPRI's president and CEO.

Before joining EPRI, Hirsch served as vice president and manager for research and technical services at ARCO Oil & Gas Company in Dallas, Texas, a position he had held since 1983. In addition, since 1986 he was chief executive officer of ARCO Power Technology, Inc., an ARCO subsidiary based in Washington, D.C., that he founded.

Hirsch's earlier experience includes six years in managerial positions with Exxon Corporation. He also was a nuclear engineer with Atomics International of Canoga Park, California, and a fusion research physicist with ITT Industrial Laboratories in Fort Wayne, Indiana.

During nine years of government service, Hirsch worked for the U.S. Atomic Energy Commission and the Energy Research and Development Administration. At the latter agency, he first served as a staff physicist, then became director of the magnetic fusion energy program, and finally was named assistant administrator for solar, geothermal, and advanced energy systems, a presidential appointment.

Hirsch has a BS in mechanical engineering and a PhD in nuclear engineering/physics from the University of Illinois. He received an MS in nuclear engineering from the University of Michigan. He holds 14 patents and has published extensively in peer-reviewed journals and books. A fellow of the American Academy for the Advancement of Science, Hirsch has been active on several petroleum, natural gas, and energy research committees, including the Department of Energy Research Advisory Board and various National Research Council study panels. ■

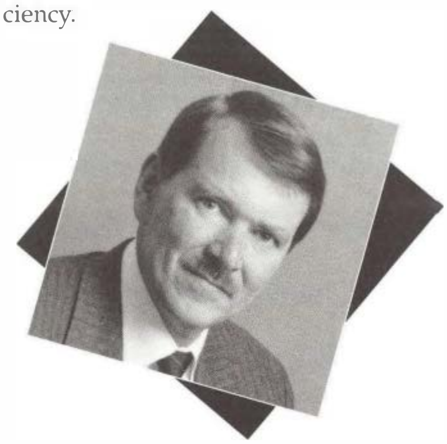
Gellings Named VP for Customer Systems

Clark W. Gellings, the former director of EPRI's Customer Systems Division, was appointed vice president for the division, effective January 3. Gellings succeeds Arnold Fickett, who has retired.

EPRI president and CEO Richard E. Balzhiser called Gellings "a DSM pioneer and a man of vision and vitality." Said Balzhiser, "Arnold Fickett has provided wisdom and distinguished leadership in his 17 years with the Institute. I'm sure Clark will continue this excellence."

This year is Gellings's tenth with the Institute. He started as manager of the Demand-Side Management Program and in 1989 became division director. Previously he worked for 14 years with Public Service Electric & Gas Company of New Jersey.

Gellings has been active in professional and government organizations. He is a fellow of the Institute of Electrical and Electronics Engineers. Among his IEEE activities, Gellings was founder and chairman of the Demand-Side Management Subcommittee and currently serves as chairman of the Power System Engineering Committee. Gellings also is a U.S. representative to the international CIGRE Working Group on Factors Affecting Growth in Electrical Load and a technical adviser to the U.S. mission to the International Energy Agency; he has been an adviser to the U.S. Congress Office of Technology Assessment panel on energy efficiency.



The recipient of seven lighting design awards from the Illuminating Engineering Society of North America and a licensed professional engineer in New Jersey and California, Gellings has authored or coauthored some 200 articles and papers.

He has a BS in electrical engineering from Newark College of Engineering, a master of management science degree from Stevens Institute of Technology, and an MS in mechanical engineering from New Jersey Institute of Technology. ■

Land and Water Quality

Predicting Toxicity in Aquatic Ecosystems

by Donald Porcella, Environment Division

When chemicals such as selenium, arsenic, and mercury enter lakes and streams, they become part of an aquatic ecosystem where complex interactions influence their toxic impact. For example, the impact of a chemical depends on its chemical form: each form has unique properties that influence availability to life-forms, uptake rates, cycling, and toxicity. Furthermore, the impact of a chemical may depend on interactions at various levels of biological organization, involving individuals, populations, or entire communities (Table 1). Scientists seeking accurate assessments of water quality have found their efforts hampered by inadequate characterization of these complex interactions.

Regulators have used biological toxicity tests to calculate water quality criteria for protecting aquatic communities. In past tests, investigators have exposed aquatic life-forms to toxicants without measuring how biological toxicity varies with chemical form. Consequently, for each toxicant, regulators have used total concentration as the water quality criterion. Now, however, technical advances in analytical chemistry are allowing researchers to measure the individual chemical forms of many important toxicants. Such measurements have improved our understanding of chemical transformations in lakes and streams (biogeochemical cycling) and of conditions that define toxicant exposure in both laboratory and natural settings. EPRI-sponsored research seeks to explain how individual responses to various chemical forms of important toxicants relate to changes in the ecosystems of lakes and streams.

ABSTRACT *Ash leachates and other utility wastes that may enter lakes or streams contain mixtures of chemicals that include several kinds of toxicants. The toxic properties of these mixtures vary with the chemical form and concentration of their constituents. EPRI is developing a general toxicity model (GTM) to simulate environmental conditions in bodies of water where toxicants are present, and to predict the effects of toxicants on aquatic life-forms and ecosystems. To date, scientists have developed analytical methods to measure ambient concentrations of the major species of trace elements (selenium, arsenic, and mercury) and a model to describe the biogeochemical role of selenium. Recent studies of selenium cycling through the aquatic food web support GTM development.*

Selenium research

The trace element selenium provides a good example of an element whose chemical form and biogeochemical cycling determine its biological toxicity. Selenium can exist in multiple oxidation states—selenate, Se(VI); selenite, Se(IV); elemental selenium, Se(0); and selenide, Se(–II)—and in multiple chemical forms within an oxidation state, such as organic and inorganic selenide. All these chemical forms of selenium can change under different water chemistry and biological influences. They differ in biological toxicity: organic selenide is the most toxic, followed by selenite and then selenate.

Although trace amounts of selenium are necessary for life, slightly higher concentrations are toxic. Selenium toxicity became an issue for the utility industry during the late 1970s and early 1980s, when selenium appeared to harm fish populations in several power plant cooling reservoirs. The first documented incident occurred at Duke Power's Belews Lake, where several species of fish failed to reproduce during 1976. Similar reproductive failures occurred in fish populations at Carolina Power & Light's Hyco Lake, and excess bioaccumulation occurred at Texas Utilities' Martin Lake.

At the Duke Power site, utility ash pond effluent carrying selenium was discharged into Belews Lake, and officials attributed the reproductive failure of fish there to the unusually high levels of selenium found in their tissues. However, despite these high levels of selenium in fish, Belews Lake—like Martin and Hyco lakes—tested below 35 μg/L for selenium, the U.S. Environmental Protection Agency water quality standard at that time. Furthermore, water quality testing at the utility lakes did not differentiate among the three major chemical forms of selenium in water, nor was it designed to detect other toxicants in the water that might have harmed fish.

To understand why fish living in certain utility lakes failed to reproduce, in the early 1980s EPRI and the utilities involved began studying the impact of toxic chemicals on fish (RP2020). Researchers considered several chemicals, but they focused on selenium, estimating its rate of accumulation in fish tissues and investigating its mechanism of toxic action. In laboratory studies, they found that excessive selenium accumulated in the ovaries of female fish, was transferred to eggs, and—during embryonic development—caused larval deformities and death. Laboratory fish, however, accumulated less selenium in their tissues and experienced less toxicity than utility lake fish did, so many questions about selenium toxicity remained unanswered.

To provide a full description of selenium toxicity, EPRI researchers began devising analytical methods of measuring the various chemical forms of selenium in water. Ultimately, they were able to measure the chemical forms of selenium in utility ash pond effluent (EPRI report EA-4641, Vol. 1) and to track the transformation of those forms in cooling lakes (EN-7281, Vol. 1). Figure 1, for example, presents and discusses results for Belews Lake. Researchers used this new information to develop a detailed biogeochemical cycling model (EN-7281, Vol. 2) that predicts how selenium exposure will vary over time for fish that live in contaminated water. They were able to show that the chemical form of selenium influenced its rate of accumulation in fish tissues and its toxicity.

General toxicity model

Building on their selenium toxicity research and the biogeochemical cycling model, EPRI researchers have begun developing a larger framework—a general toxicity model (GTM). The GTM aims to help scientists assess the toxic impact of chemical mixtures on lake and stream ecosystems (Figure 2). The study of selenium provides a good test case for GTM development for three reasons: selenium's complex chemistry influences its biological toxicity, an excellent selenium database exists, and selenium is of immediate concern to utilities.

Developing the GTM requires scientists to coordinate studies in toxicology with work in numerical modeling. As the experimental understanding of selenium cycling and toxicity improves, researchers can use the results to guide further numerical development of the GTM. At the same time, they can use the model to perform numerical calculations that integrate research results, test hypotheses, and suggest more-accurate experiments in toxicology.

Table 1
FACTORS AFFECTING TOXICANT IMPACT

Level of Biological Organization	Factor
Individual	Chemical form
	Amount of chemical
	Net accumulation
	Distribution in tissues
	Physiological mechanism(s) of action
Population	Differential species sensitivity
	Reproductive strategy
	Population size and age distribution
	Timing of exposure
	Other stresses
Community	Number of populations
	Diversity
	Complexity of interactions between populations
	Other stresses

For each component of the GTM, researchers conduct numerical modeling experiments simulating lake and stream conditions in order to identify key parameters that affect model performance. According to sensitivity analyses, a key parameter is one whose coefficients in simulations that meet model performance criteria differ significantly from its coefficients in simulations that fail to meet the criteria. Identifying key parameters and defining interactions between input variables through the use of multivariate statistical techniques can help researchers design experiments to improve the GTM.

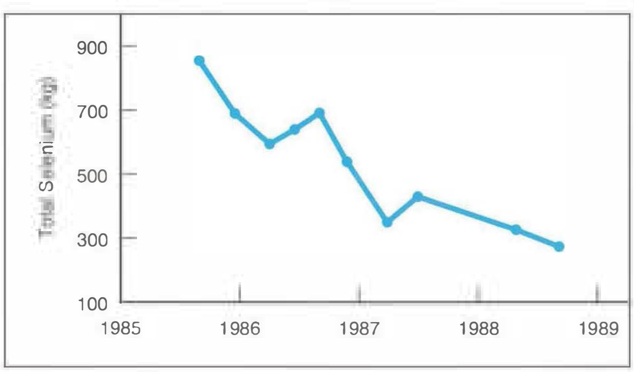
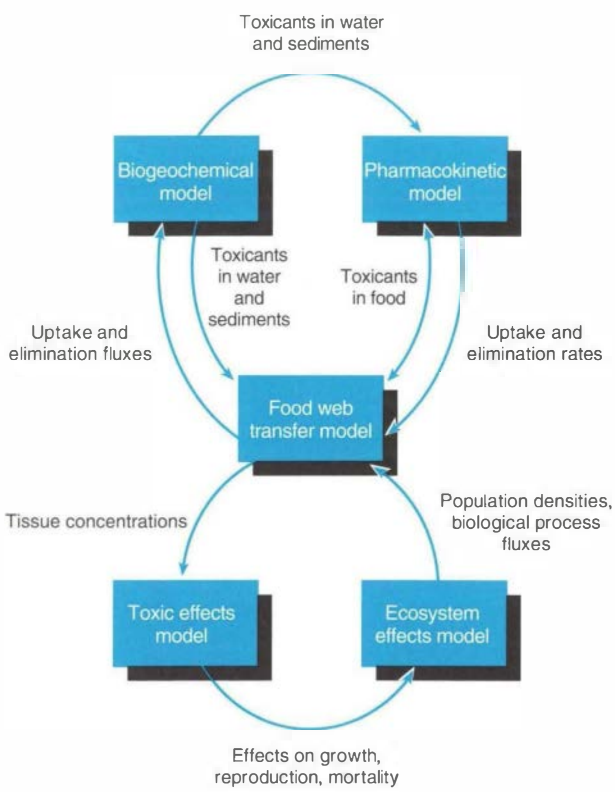


Figure 1 The total selenium in Belews Lake water has decreased since 1985, when the practice of discharging ash pond effluent into the lake was stopped. According to measurements begun that year, selenite (the dominant form of selenium in cooling lakes that receive ash leachate) is chemically reduced to elemental selenium in the deeper, oxygen-poor layers of water and sinks into lake bottom sediments. The sediments act as a reservoir for the elemental selenium, a nonsoluble form that only slowly changes into soluble forms that can reenter the lake water.

Laboratory experiments

Like the GTM, the experimental program supporting model development

Figure 2 The GTM has five major components. The biogeochemical model predicts toxicant exposure conditions. The pharmacokinetic model predicts toxicant accumulation in aquatic life-forms under given exposures; it includes a physiological model for predicting the distribution of toxicants in fish tissues. The food web transfer model tracks toxicant movement through the aquatic food web. The toxic effects model predicts the effects of toxicant exposure on the growth, reproduction, and mortality of aquatic life-forms. Finally, the ecosystem effects model predicts the impact of toxicant accumulation on aquatic populations and communities.



takes an ecological perspective in assessing selenium toxicity. The program covers all major trophic groups—strata associated with nutrient transfer and feeding—in lake ecosystems, including microbial life-forms (bacteria, ciliates, rotifers, and flagellates), phytoplankton (diatoms and green and blue-green algae), invertebrates (a zooplankton and a bottom-dwelling insect), and several fish species that occupy different levels in the aquatic food web and reproduce by different mechanisms. The experiments are exploring selenium accumulation, selenium toxicity, and the effects of biological factors on selenium cycling. Scientists plan to integrate the study of several trophic groups in microcosm experiments in the laboratory. Such laboratory work, together with field experiments, can provide the quantitative information researchers need to estimate parameters in the GTM.

To discover the fate of selenium as it passes through successive trophic groups, researchers use uptake/elimination experiments and toxic effects experiments. Uptake/elimination experiments measure the rates of uptake, elimination, biochemical transformation, and net accumulation of selenium in members of a trophic group exposed to various chemical forms of selenium in water, sediments, and contaminated food sources. For example, researchers might quantify the rates of decomposition and oxidation-reduction reactions involving microbes exposed to various forms of selenium. These experiments reveal the major biological pathways and transport mechanisms that carry selenium through freshwater ecosystems. They extend EPRI's earlier biogeochemical research on selenium (RP2020-1).

Toxic effects experiments measure the impact of important chemical forms of selenium on members of a trophic group throughout their life cycle. In these experiments, scientists study the effects of selenium on the survival, growth, reproduction, and larval viability of aquatic life-forms. A research program cofunded by EPRI and Carolina Power & Light (RP2020-6), as well as one funded by the U.S. Fish and Wildlife Service, complement these ongoing studies.

In designing and conducting experiments on biogeochemical and pharmacokinetic processes at lower levels in the aquatic food web, scientists are pursuing an understanding of the higher-level processes that affect selenium accumulation in fish. To date, the experimental work on microbial life-forms and phytoplankton has yielded the following key results:

- Selenium uptake by life-forms at lower levels in the aquatic food web varies in amount

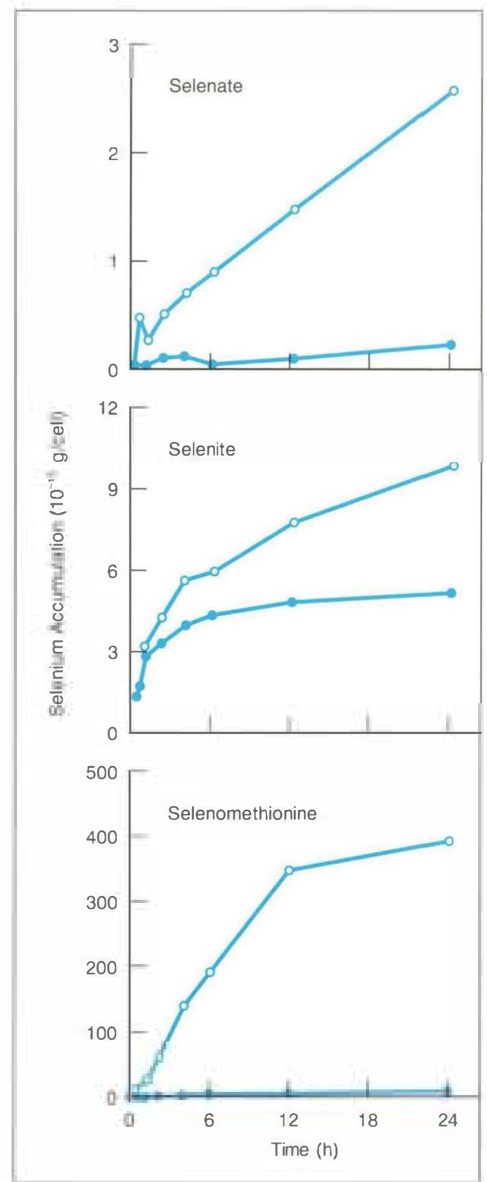


Figure 3 Laboratory experiments examined how the diatom *Cyclotella* takes up three forms of selenium. Open circles indicate living diatom cells; filled circles, dead cells. Living cells take up all three forms—but at different rates and in amounts that differ by orders of magnitude (note the vertical-axis scales). Dead cells take up virtually no selenate and selenomethionine, indicating that uptake of these forms relies on metabolism. Dead cells do accumulate substantial amounts of selenite by adsorption.

and rate, depending on the chemical form of selenium in the water. Figure 3, for example, illustrates the marked differences in the way the diatom *Cyclotella* takes up selenate, selenite, and selenomethionine. Neither microbial life-forms nor phytoplankton show toxic responses to these forms of selenium at the concentrations found in utility cooling lakes.

- For microbial life-forms and phytoplankton, environmental factors that determine water chemistry (such as pH and concentrations of sulfate and phosphate) significantly affect the uptake of some chemical forms of selenium but not others.
- Inorganic forms of selenium, such as selenite, may reversibly bind to the cells of bacteria and algae by a process of adsorption. Irreversible incorporation into organic cell components requires the biochemical transformation of selenite.
- Some species of bacteria and algae convert selenium to dimethylselenide, a volatile chemical form that escapes water as a gas. The escape of gaseous dimethylselenide can affect the concentration of selenium in lakes and streams.

Future directions

By coupling numerical modeling with laboratory experimentation, researchers have reached some important conclusions after completing only the first major steps in the GTM development program. For example, scientists now understand that water chemistry and biochemical transformations of selenium influence its accumulation in the tissues of aquatic life-forms—and therefore determine its impact on the ecology of lakes and streams.

Likewise, scientists have confirmed that nutrient supplies control the growth rate of aquatic life-forms and therefore influence the accumulation of selenium in the tissues of these organisms. They have demonstrated that the GTM must incorporate nutrient cycling in order to predict selenium toxicity. Finally, scientists now appreciate the need to study several organic forms of selenium because the common laboratory tracer (selenomethionine) behaves differently than the selenopeptides and other organoselenides secreted by aquatic life-forms or released during their decomposition.

The approach adopted by EPRI researchers in studying selenium is applicable to other chemicals that may have toxic effects on aquatic ecosystems. Other potential toxicants include the metals cadmium, chromium, and copper; the metalloid arsenic; and numerous organic compounds. Expanding the GTM to describe the ecological impact of each of these substances would create a framework for solving the broad range of problems utilities encounter when their power plants discharge wastewaters into lakes and streams.

Steam Generator Reliability

Modeling Crevice Chemistry in PWR Steam Generators

by Peter J. Millett and J. Peter N. Paine, Nuclear Power Division

The accelerated corrosion of steam generator materials has resulted in unplanned outages and the premature replacement of steam generators at several operating pressurized water reactors (PWRs). The corrosion may occur under various conditions that produce different types of attack, such as pitting, stress corrosion cracking, wastage, and denting.

Corrosion results when a susceptible material is exposed to aggressive environmental conditions. In steam generators, the corrosion usually occurs in local crevices and occluded regions, where monitoring the water chemistry is difficult. The alternative is to infer or predict the local chemical environment from the steam generator bulk water chemistry, which is easier to monitor. EPRI sponsored the development of the MULTEQ code to help plant chemists and engineers understand the mechanisms of corrosion more clearly and predict the local water chemistry in steam generators. An improved understanding should eventually allow utilities to reduce corrosion by manipulating steam generator water chemistry.

Most steam generator corrosion occurs locally in flow-restricted crevices and under deposits, where impurities concentrate because of restricted boiling. Typically, steam generator water is very pure, containing only trace levels of impurities. In the residual crevice liquid, however, many impurities can increase in concentration by several orders of magnitude, producing an aggressive solution.

Many processes are involved in the corrosion of steam generator materials. Among them are chemical and electrochemical reactions at the metal-liquid interface and possibly at the metal-steam interface. Fluid dynamics, heat transfer, and mass transfer also play important roles in regulating the concentration process and the underlying corrosion mechanism. Knowing the composition of the solution in the crevice is critical for understanding the overall corrosion process. The kinetic and transport processes that control the rate of damage are a function of the solution composition. All these phenomena must be investigated in order to understand and control corrosion fully.

The MULTEQ code

A complete a priori predictive model of steam

Table 1
SEAWATER COMPOSITION

Species	Concentration (ppm)
Sodium	10,561
Magnesium	1,272
Calcium	400
Potassium	380
Chloride	18,980
Silica	7
Sulfate	2,649
Carbonate	142

generator corrosion is not yet possible because we lack the necessary understanding of all the factors involved. However, considerable insight into methods of controlling corrosion should be possible if we can predict certain key parameters, such as the solution pH. The MULTEQ code is designed to make such predictions.

MULTEQ contains a simplified model of the concentration process that occurs as water from an aqueous solution evaporates. This model assumes that the system is of uniform composition and temperature and is in thermodynamic equilibrium at all times. The model accounts for ion-complex formation, solute precipitation, and distribution of the volatile neutral species into the steam phase. One version of the code (MULTEQ-Redox) considers electrochemical oxidation-reduction reactions. All these processes are important because they dictate the composition of the aqueous phase, where corrosion occurs.

MULTEQ is an outgrowth of a code developed under EPRI contract at the Central Electricity Research Laboratories in England. Researchers at Brigham Young University and at S-Cubed developed the code further for EPRI.

The development of MULTEQ had two components. One was to construct a thermochemical database that would make it possible to specify the desired chemical species, composition, and temperature in a user-friendly manner. The second component was to increase the reliability of the code by using robust numerical methods.

Updating and improving the thermochemical database are ongoing activities. A committee of experts from industry and academia was formed to review the database critically and recommend new chemical species and data. Because of the scarcity of the kind of reliable high-temperature chemistry data MULTEQ requires, the database committee has made careful extrapolations of low-temperature data from the literature when necessary. Under EPRI sponsorship, several laboratories also have contributed to the database by making direct high-temperature measurements of important chemical systems. In addition, the code has been refined in many ways to increase its usefulness. MULTEQ and MULTEQ-Redox are available for IBM PCs (and compatibles) and workstations and can be specially adapted for other computer platforms.

ABSTRACT *In PWR steam generators, corrosion tends to occur in local crevices and occluded regions, where it is difficult to monitor water chemistry. With the right analytical tools, however, plant chemists and engineers can infer the local chemical environment by analyzing the steam generator's more easily monitored bulk water. MULTEQ, an EPRI-developed code, helps plant personnel predict key parameters that affect corrosion, such as solution pH. With several model options, MULTEQ users can investigate how impurities accumulate in crevices and occluded regions during plant operation. The code will support efforts to identify new water chemistry technologies.*

Table 2
HIDEOUT-RETURN CHEMISTRY

Species	Concentration (ppb)
Sodium	75
Magnesium	3
Calcium	14
Chloride	13
Silica	156
Sulfate	13

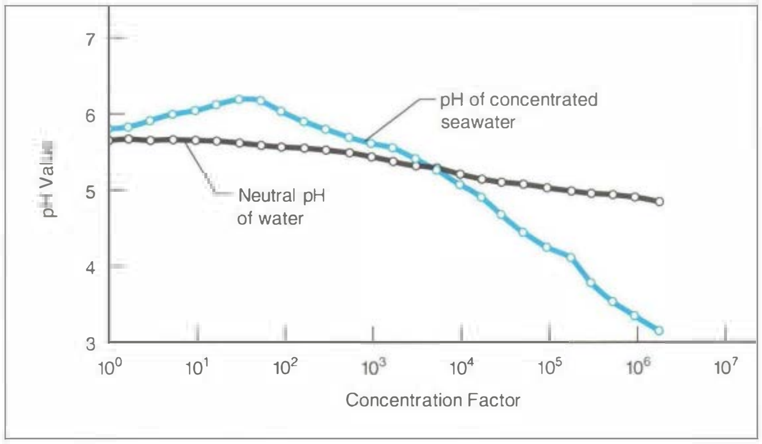
Modeling the concentration process

MULTEQ has several model options for describing the process by which impurities accumulate in crevices and occluded regions. These models include a closed system, with no flow into or out of the crevice; a model in which solids precipitate and/or steam is removed from the crevice; and one in which fresh water flows into the crevice and steam leaves the crevice, taking with it those species that have distributed into the vapor phase and leaving behind many impurities that become concentrated with time. Though these models represent the concentration process in slightly different ways, they all describe the crevice chemistry as a function of the concentration factor.

The concentration factor can be simply defined as the ratio of the initial mass of liquid in a system to the current mass of liquid in the system. For example, when a drop of water evaporates or boils on a hot surface, the initial concentration factor is unity. As the water boils, the fraction of liquid decreases; the concentration factor approaches infinity as the last bit of water evaporates. In an operating steam generator, the concentration factor is limited by external factors, such as the operating temperature in the primary system. As the solution in the crevice becomes concentrated, its boiling point increases. Eventually the boiling point reaches the primary-system temperature, and boiling is locally arrested. Concentration factors of 10^4 to 10^8 and greater are typical in the field and have been measured in the laboratory for simulated crevices.

The liquid in a steam generator contains a variety of chemical species, which may be additives or impurities in the system. As the local concentration process goes on, some species in the liquid phase increase dramatically in concentration. Other species may volatilize into the steam phase. Still other compounds may precipitate from solution. All these processes determine the composition of the remaining liquid. At each concentration factor, MULTEQ calculates the thermodynamic composition of the liquid, vapor, and solid phases. Of most interest is the composition of the liquid phase, since it is primarily responsible for corrosion of the steam generator tubing and other materials.

Figure 1 MULTEQ was used to predict the local pH in a PWR steam generator crevice for a case involving a condenser tube leak in a seawater-cooled plant. Initially the pH of the seawater in the crevice is near neutral for the solution's temperature. (The black curve shows the neutral pH for water of comparable temperature and ionic strength.) After several cycles of concentration, the crevice solution becomes acidic, and the initiation of acid forms of corrosion is possible.



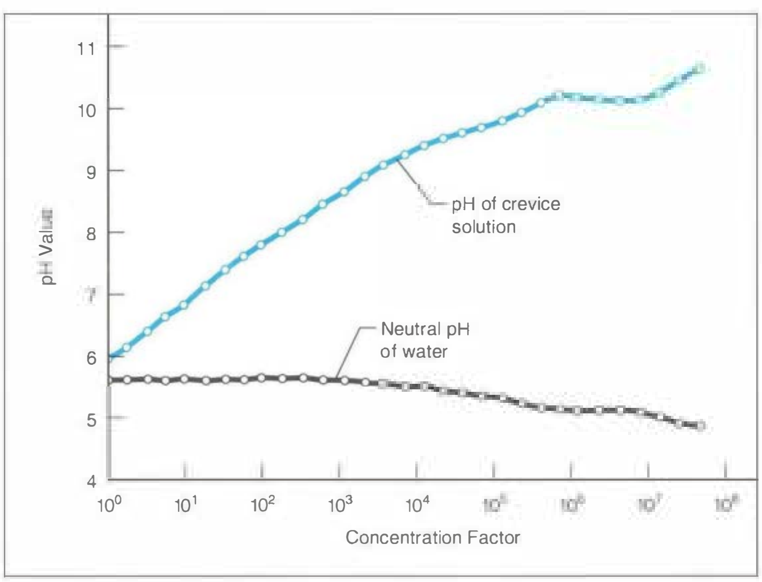


Figure 2 MULTEQ can be used to predict crevice chemistry on the basis of bulk water impurities measured during hideout return. At this plant, the crevice chemistry is very alkaline after several cycles of concentration—conditions that could result in the initiation of stress corrosion cracking.

MULTEQ applications

The need to predict or monitor crevice chemistry can be demonstrated by two simple examples. The first illustrates the effect of a condenser tube leak in a plant cooled by seawater. Table 1 gives the seawater's composition. For the MULTEQ simulation, the concentrations in Table 1 are diluted by a factor of 10^4 to account for the dilution of the seawater in the secondary system. Figure 1 illustrates the predicted behavior of the seawater solution after several cycles of concentration.

As noted earlier, solution pH is one important parameter that affects corrosion. Initially the pH of the high-temperature (270°C) crevice solution is close to the neutral pH of water at that temperature—namely, 5.6. (The neutral pH of water varies with temperature; at room temperature, it is about 7.) After several cycles of concentration, however, the solution pH drops to near 3, whereas the neutral pH of water drops to only about 4.8. Under these circumstances, we can expect the initiation of acid forms of corrosion. In fact, many plants cooled by seawater have experienced denting- and pitting-type corrosion during periods of condenser in-leakage.

Various compounds will precipitate from solution at given concentration factors. In the case of Figure 1, the drop in pH results from the hydrolysis of magnesium salts in seawater, which produces insoluble magnesium hydroxide and hydrochloric acid. The acid can initiate corrosion, which may then generate more acidity in situ.

At the other extreme is an example of hideout-return chemistry from an operating plant. Hideout return refers to the return of impurities from crevices to the bulk water during a shutdown. Measurements of the hideout-return species in the bulk water—as in Table 2, for example—can be used as input to MULTEQ. Figure 2 shows the crevice chemistry predicted on the basis of this observed hideout-return bulk water chemistry. After several cycles of concentration, the crevice chemistry is very alkaline. The pH of the high-temperature crevice solution at a concentration factor of 10^6 is nearly 5 units greater than the neutral pH of water. Under these conditions, the initiation of caustic-induced stress corrosion cracking is likely. Indeed, cracking did occur at the plant in this example.

Crevice chemistry control

One goal of EPRI's steam generator reliability research is to identify new water chemistry technologies that will buffer the adverse effect of impurities in the system. MULTEQ can help in this search. By determining how various chemicals interact in the crevice environment, researchers can identify the required properties of additives. The ability to screen compounds with MULTEQ before running expensive experiments can reduce research costs.

Another important application of MULTEQ is to specify the optimal level or ratio of impurities in the system for producing a balanced water chemistry. The goal is to produce a crevice pH near neutral, a level that is less aggressive than the acid and caustic environments shown in Figures 1 and 2. MULTEQ can also be effective in evaluating the results of laboratory corrosion tests involving simulated crevice chemistries. Correlations have been improved when researchers have evaluated laboratory corrosion data in terms of the high-temperature chemical environment predicted by MULTEQ.

These and other applications of MULTEQ can help identify the optimal water chemistries and materials for prolonging the life of existing and future steam generators.

Demand-Side Management

Prospects for Standby-Power Programs

by Michael Evans and Phil Hanser, Customer Systems Division

To support utility efforts to expand service options and tailor them to customer needs, EPRI recently took a close look at standby power—a strategy for reducing peak power loads that utilities may not have explored fully. The EPRI study yielded a key finding: combining an interruptible rate program with new or existing customer backup generating capacity holds tremendous potential for a win-win marketing strategy that benefits utilities and customers alike.

Surprisingly, the study concluded that only a small percentage of customers with high outage costs now have backup systems. Providing a high-reliability service option that combines backup generation assistance and interruptible rate incentives could help utilities better meet the needs of these customers.

ABSTRACT *As utilities seek to develop a full range of energy service options, one important choice to consider is a program that provides customers with premium reliability through on-site backup generating capacity and interruptible rate incentives. For utilities, such programs help avoid expensive capital investments by reducing peak power demand. For customers, they can virtually eliminate the impacts of high outage costs. Recent EPRI research shows that incentive standby-power programs are easy to develop, that the technology is simple and low cost, and that an ideal market already exists—a large, untapped pool of customers with high outage costs.*

A recently published EPRI report, *Customer Backup Generation: Demand-Side Management Benefits for Utilities and Customers* (CU-7316), explores these findings in some detail. The report provides valuable guidance for an electric utility that is considering adding this premium service product to its portfolio of energy services. In the past, utilities have used outage cost surveys for general planning purposes only. From this new perspective, the value-of-service concept can serve as a basis for structuring a menu of rate options to meet differing customer needs for service reliability.

Identifying the benefits of backup generation

Current backup generation technology is reliable, easy to install, and relatively low in cost. An alternative to cogeneration that offers considerable cost advantages and higher reliability, backup generation meets critical customer needs, protects the utility from a potential loss of revenue, and provides a new load management tool.

Backup generation allows customers to take advantage of lower utility rates for interruptible service, thereby reducing their annual electricity costs. (This saving is generally $50 to $60/kW/yr.) Backup generation also offers increased reliability and reduced outage costs. Often a major expense (yet one that is sometimes overlooked), outage costs can be reduced by at least 90%. For many customers, this potential benefit is far more important than the savings in their electricity bill. Customers must weigh these benefits against the estimated annualized cost of installing backup generation—$76/kW.

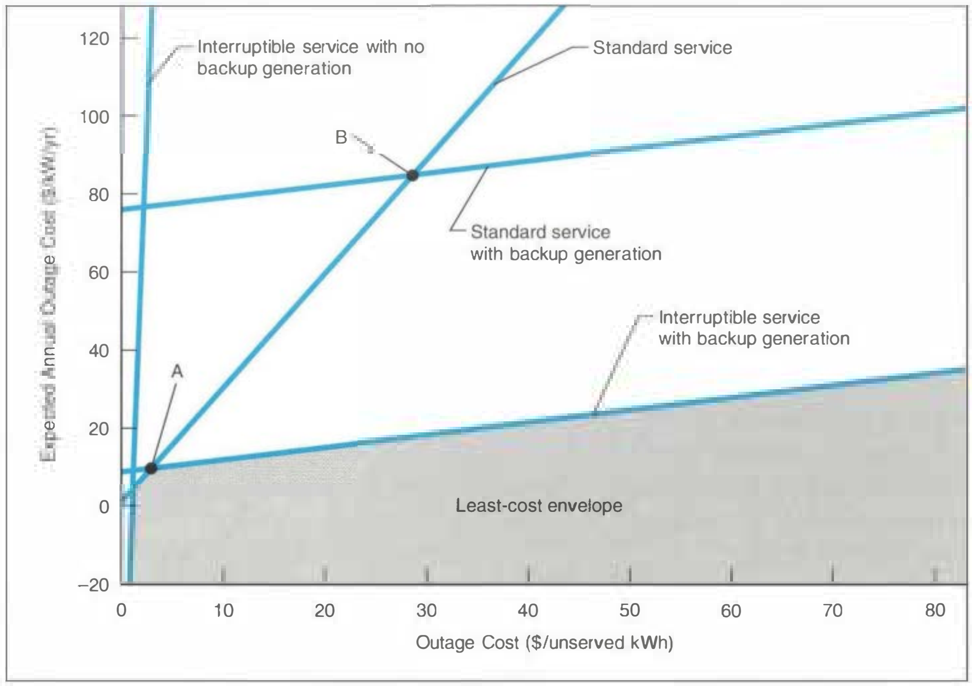
Backup generation is a powerful tool for utilities as well. It allows them to reduce peak power demand and meet peak load requirements at a lower cost than they would pay for new generating capacity. It may also allow them, in some circumstances, to defer transmission and distribution upgrades, thereby more than doubling the value of avoided peak capacity costs. Furthermore, utilities can structure customer use of backup generation to coincide with the relatively small number of peak demand hours. This mitigates the potential for customers to install cogeneration or to attempt to shave their own peak loads, approaches that can involve several hundred to a few thousand hours of operation a year.

The EPRI study illustrates the potential of backup generation as a demand-side management technique and presents the key specifications utilities need to develop a new service offering. At the same time, the report takes care to consider how the customer will evaluate a backup generation program. For example, important practical issues related to installing backup generation are explored from the customer's perspective.

In a straightforward manner, the report provides tools and information to help utilities promote backup generation. It includes:

- A complete chapter on backup generation technology.
- A method of analyzing the benefits and costs of backup generation from the customer's viewpoint, including a sample customer worksheet.
- Insights into customer motivation to help utilities market backup generation programs.
- A review of ongoing utility programs that offer interruptible rate incentives. Case studies closely examine two such programs that have been successfully combined with customer backup generation, and five more programs are described in some detail.

Figure 1 Analysis of four service options (assuming an outage probability of 4.8 hours a year and an annualized backup generator cost of $76/kW). The utility offers an aggressive interruptible rate incentive but no additional incentive for backup generation. A customer whose outage cost exceeds $3.50 per unserved kWh (point *A*) can justify choosing interruptible service and purchasing backup generation equipment. With standard service (no interruptible rate incentive), backup generation is justified if the customer's outage cost exceeds $28 per unserved kWh (point *B*).



Analyzing benefits and costs

A customer-focused analysis of the costs and benefits of backup generation yields four key findings:

- Customers with very high potential outage costs (i.e., more than $100/kW/yr) can be expected to install backup generation without special utility incentives.
- Customers with middle-range outage costs cannot economically justify backup generation without some utility incentives.
- Most current utility interruptible rate programs do not justify customer investment in backup generating capacity unless the customer's outage costs are high (i.e., more than $80/kW/yr).
- Utility interruptible rate programs are attractive to customers that lack backup generating capacity only if the customers' outage costs are very low.

Figure 1 presents a service option analysis for a specific service territory, customer outage probability (4.8 hours a year), and annualized backup generator cost ($76/kW). The interruptible rate schedule calls for 75 hours of interruption a year with a net credit of $67/kW (an $84/kW credit minus a $17/kW penalty).

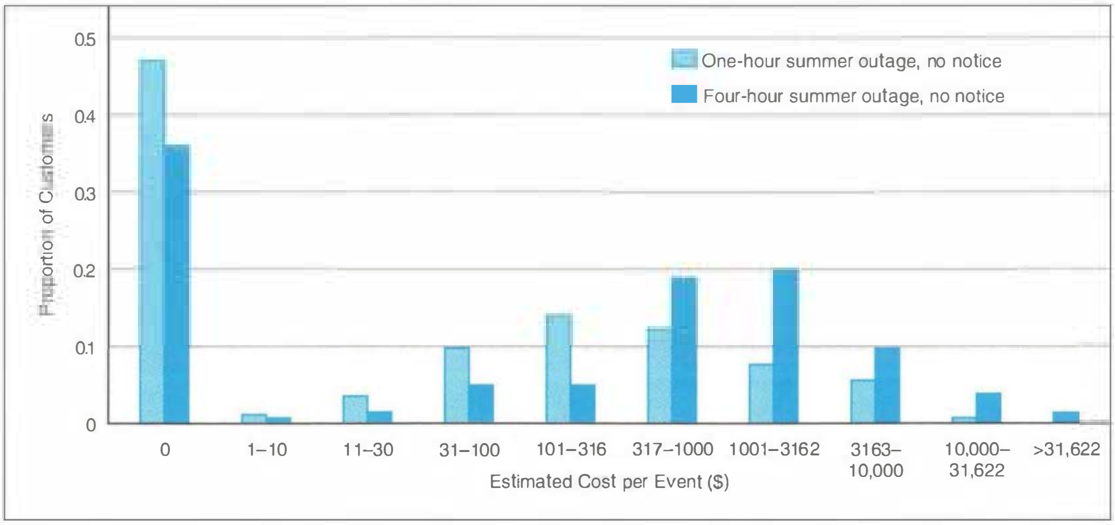
In this case, in which the utility offers an aggressive interruptible rate incentive but no additional incentive for backup generation, a customer with an outage cost exceeding $3.50 per unserved kWh (point *A*) can justify an interruptible rate and the purchase of a backup generator. Without the interruptible rate incentive (i.e., with standard service), backup generation is justified if the customer's outage cost exceeds $28 per unserved kWh, which translates to $84/kW/yr (point *B*). Any incentive to purchase a backup generator and/or to accept an interruptible schedule lowers the outage cost at which backup generation is justified (as shown above with the $67/kW rate incentive).

Looking at costs and benefits from the utility viewpoint leads to three major conclusions:

- Utilities that need peaking capacity may be able to meet those needs at lower cost by using customer backup generators than by installing additional combustion turbines, a common solution for meeting peak load requirements.
- Utilities can share the financial benefits of backup generation with customers: customer outage costs are reduced, and the utility avoids increased capacity costs.
- Utilities also can benefit from targeting customers in overloaded or rapidly growing parts of the distribution system. The distribution-related benefits of a well-focused program can often justify incentive payments similar to those offered by utilities that need peaking capacity.

Table 1 illustrates the costs and savings that the customer and the utility might realize. Utility savings are mainly due to the avoided costs of additional generating capacity and distribution system upgrades, such as substation expansion. In this case the customer has very high outage costs, and the credit offered by the utility to the customer has not been specified.

Figure 2 Distribution of outage costs per event for small and medium-size commercial customers (typically with loads of less than 100 kW). The average outage cost for such customers was estimated to be $30 per unserved kWh. The sizable fraction of customers with outage costs of more than $300 per event presents an ideal target market for installing new backup generating capacity. (M. Sullivan, "Commercial Value-of-Service Study," preliminary draft results, Pacific Gas and Electric Company, San Francisco, California, August 1990.)



Identifying a target market

Interruptible rate programs often are mistakenly seen by utilities and customers as a low-cost, low-reliability service option. However, when combined with backup generation, they offer a very high reliability option and, for many customers, a reduction in total costs.

Utilities can take advantage of this combination to greatly expand subscriptions to their interruptible rate programs and maximize program effectiveness. To be effective, programs must explicitly recognize the very high internal outage costs of certain customer segments. They must also promote backup generation to these customers as a way to enhance the value of service through increased reliability.

Recently several utilities have had significant success in marketing interruptible rate programs to customers with existing standby generation. Few, if any, utilities have developed programs that explicitly target customers who have no backup generators and who face high internal outage costs—the very customers who will perceive the highest added value. Figure 2 illustrates a typical distribution of commercial customers' outage costs. It shows that a sizable fraction of customers have outage costs greater than $300 per event. These customers are the target market for installing new backup generating capacity.

Moreover, as a result of technological ad-

Table 1
BENEFITS OF CUSTOMER BACKUP GENERATING CAPACITY
($/kW/yr)

	Customer Benefit	Utility Benefit	Net Benefit
Reduced outage costs	+202	0	+202
Generator capacity costs	−76	+82	+6
Generator operating costs (fuel and O&M)	−6	0	−6
Avoided utility fuel costs	0	+4	+4
Distribution costs	0	+99	+99
Lost electricity sales revenue	+10	−10	0
Customer credit	+X	−X	0
Total	$130+X	$175−X	$305

vances in computer controls, equipment reliability, remote dispatching, and remote system-monitoring techniques, using backup power has become an attractive option for a wider variety of commercial and industrial customers. Customers with on-site engineering staffs are excellent candidates for backup generation programs. Smaller customers may also be an appropriate market if the utility program includes an operating and maintenance contract for the standby-power equipment. More-direct support, such as financing or leasing the backup system, might also be considered.

In addition, recent advances in electronic controls and coded radio signaling have increased the technical feasibility and acceptability of remotely dispatched backup generation systems. Such control gives utilities greater assurance that they can achieve load reductions when necessary. Today, although standby-power programs produce several hundred megawatts of generating capacity, almost none is directly dispatched by utilities. In the case of new backup generation systems, utilities may want to offer customers incentives to make the systems dispatchable. In the case of many existing systems, the enhancements necessary for utility dispatch can readily be added for $40 to $80/kW plus installation costs.

Guidance for utilities

Although earlier value-of-service studies have estimated outage costs for general classes of customers (see EL-6791), the new customer backup generation study applies the value-of-service concept to individual customers. The report defines three components of customer costs: expected outage costs, adaptive response costs (i.e., backup equipment costs), and utility program credits. A worksheet shows how to calculate each component as well as the overall cost.

An easy-to-use table presents key data on 14 existing interruptible rate programs, including terms of eligibility, number of participants, total interruptible capacity, number and duration of interruptions each year, means of notification and/or utility control, amount of advance notice, incentive payments, penalties for nonperformance, annual customer savings, capacity reductions, and additional customer services. The names and phone numbers of utility program contacts are also included.

To help utility marketing staff support customers in exploring equipment options for standby power, the report presents capital costs, specifications, and manufacturers for each of the four primary components of a complete backup power system: a prime mover (commonly a diesel engine), a generator, generator set controls (transfer switch or switchgear), and fuel storage tanks. Technical descriptions of state-of-the-art generator systems clarify how their cost and performance can fit into the customer's and utility's overall operations. In addition, the report explores the relationships between major manufacturers, packaging companies, and application/engineering firms for each class of equipment.

To implement a standby-power program, utilities may want to develop detailed market segmentation information that targets customers with high outage costs, a varied rate structure that provides customers with a range of cost and reliability options, and a customer service campaign that targets high-outage customers in heavily loaded sections of the distribution network. EPRI's new report provides basic information on these and many other aspects of program development.

Fossil Plant Operations

Compact Simulator Technology

by Roy Fray and Murthy Divakaruni, Generation and Storage Division

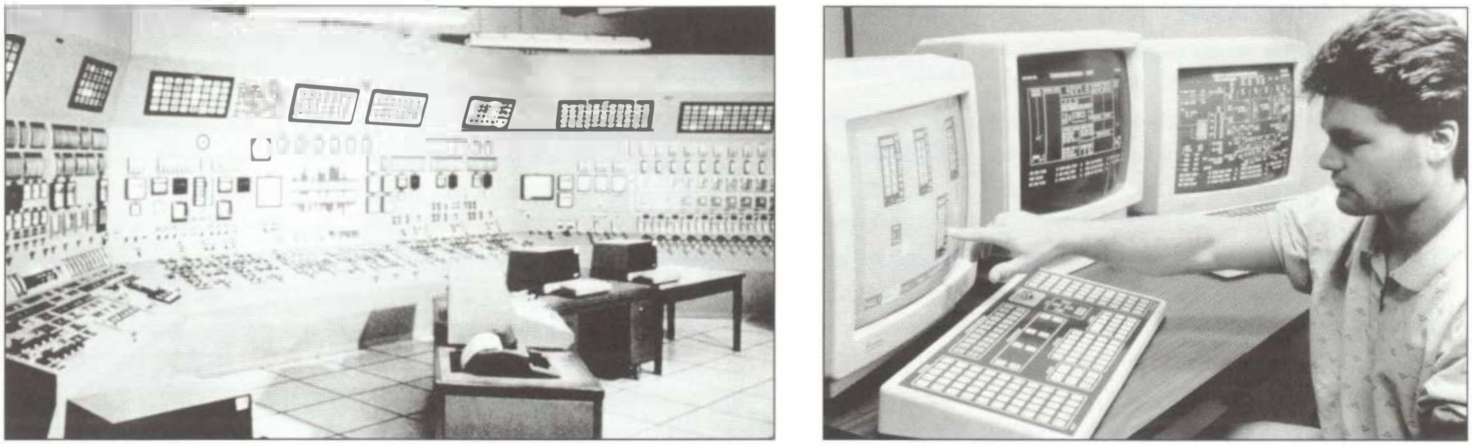
As utilities upgrade older fossil-fired plants with modern control systems, plant operators need additional training and practice. Plant engineers also need test-beds to design, verify, and pretune new controls. Conventional simulators, like the one shown in Figure 1 (left), can provide such training and test-bed facilities. Until recently, however, simulators for fossil plants have been expensive, costing $1 million to $3 million or more.

Today many utilities are turning to EPRI's compact simulator technology—simulators that are less expensive, more flexible, and more effective (Figure 1, right). Compact simulator technology has reduced simulator cost to $600,000 or less yet provides a near-replica simulator: the trainee sees the same screens, pushes the same keys, and experiences the same dynamics that he or she would experience in the actual control room.

The option of a less expensive simulator is leading to the expanded use of simulators in the fossil generation industry. After simulator training, operators are more knowledgeable, more confident, and less prone to error than they were before training (Figure 2). As a result, plant performance is improved, and operation and maintenance (O&M) costs are significantly reduced. Substantial capital cost savings also are possible when simulators are used in designing, verifying, testing, and pretuning control systems.

O&M savings can be quite large. For example, 11 utilities estimate that they will save $236 million in operating costs during the next

Figure 1 Conventional, mainframe-based simulators (left) for training fossil plant operators are expensive and inflexible. EPRI's new compact simulator technology (right) uses personal computers to provide effective training at much lower cost.



10 years by implementing compact simulator technology for 47 units. These savings are documented in several EPRI *first use* and *Innovators* publications (FS9088B; IN-1001-46, -47, -48).

Utility demonstrations

EPRI is demonstrating compact simulator technology at a number of utilities, including Alabama Power, Boston Edison, Consolidated Edison, Duke Power, Florida Power & Light, Public Service Electric & Gas, South Carolina Electric & Gas, and Southern California Edison. A host utility group of more than 15 utilities has been assembled for further development and demonstration of the technology. Every application by this group aims to enhance the technology—for example, by developing new plant process models, control system interfaces, or computer graphics tools. Other objectives are to develop an expert system to serve as an instructor; to use high-definition, ultrabright television projection to emulate control panels; and to implement an advanced, mobile simulation system.

By involving numerous host utilities, EPRI expects to demonstrate the effectiveness and benefits of compact simulator technology for a wide variety of utility objectives, fuels, boilers, turbines, and control systems. As more utilities join the program, EPRI will compile a library of compact simulator models that other utilities can use or modify. The next meeting of the host utility group will be held April 6–7, 1992, in Orlando, Florida.

ABSTRACT *In its work to expand and enhance simulator-based training in the fossil generation industry, EPRI is developing compact simulator technology for training power plant operators. These personal computer–based systems are more flexible and much less expensive than conventional, mainframe-based simulators, and their use can dramatically increase operator effectiveness. The potential benefits for utilities include improved plant performance, availability, life, and environmental compliance and thus significantly lower O&M costs.*

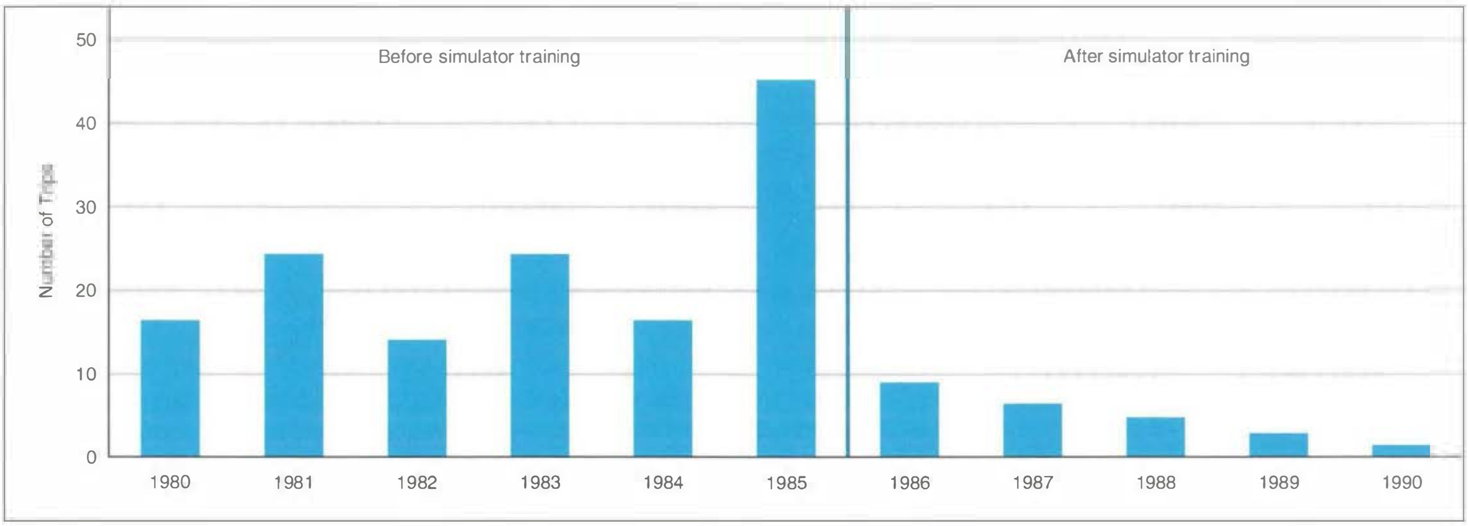
About the technology

In a typical compact simulator configuration (Figure 3), the system sits on a personal computer (PC) platform and uses a local area network to interconnect individual PCs. A configuration and parameterization program is used to build the simulation model, which is embedded in a real-time executive program with full instructor functions. A graphic screen editor is used to build operator displays and link dynamic fields on the displays to a simulation.

By replacing mainframe platforms with PC platforms, compact simulator technology capitalizes on the advantages of PCs—increased computing power at decreased cost. Model building and execution take place on IBM PC or compatible hardware using an OS/2 operating system.

Compact simulator technology replaces custom modeling with automated, modular modeling. This approach allows users to construct high-fidelity, real-time, unit-specific simulations efficiently and inexpensively. First-principle models are formulated from mass, energy, and momentum balances as well as

Figure 2 Operator-preventable trips at a three-unit station before and after operator simulator training. The number of these trips dropped dramatically in the first year of training and decreased in each following year.



appropriate constitutive relationships. Such models accurately predict the behavior of plant processes and associated control systems.

EPRI has based several compact simulators on the commercially available PC-TRAX simulation system (although it plans to interface compact simulator technology with other simulation software packages as well). For the benefit of its member utilities, the Institute has obtained a license for PC-TRAX—a high-fidelity system designed specifically for building simulations of fossil plants (see EPRI report GS/NP-6670). This type of system provides rigorous component models, property routings, run-time executives, and model-building programs. Equations describing component operation are based on fundamental, one-dimensional, lumped-parameter conservation of mass, energy, and momentum. Detailed steam and gas properties,

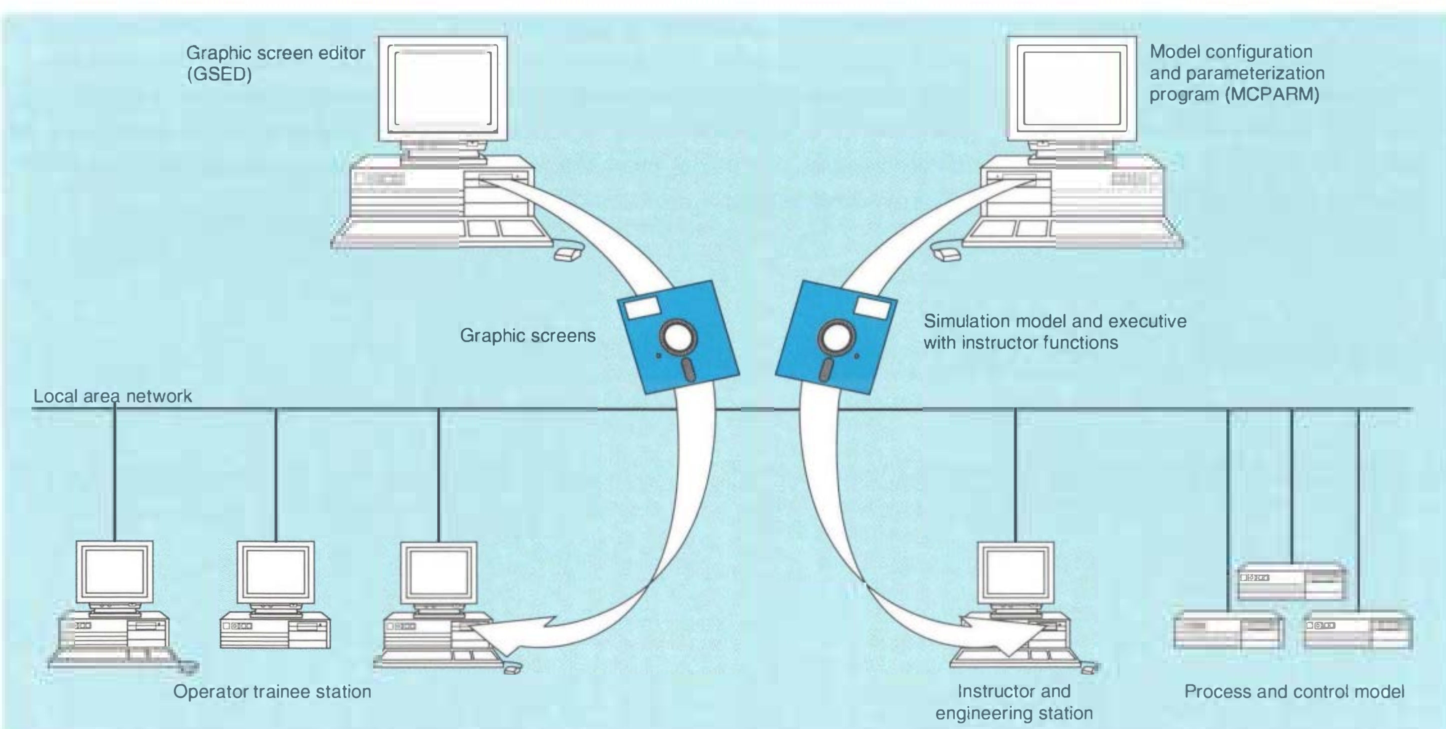


Figure 3 Typical compact simulator configuration. Personal computers are used to build and run unit-specific simulation models, as well as the graphic screens that mimic control system panels and displays.

along with well-accepted constitutive equations for heat transfer and fluid mechanics, are used in conjunction with the conservation equations. Typically, transfer function modules (i.e., modules based on observed or hypothesized responses to inputs) are not used.

The system includes routines to configure, parameterize, and execute models, as well as a library of component models. Users retrieve a component model from the library and parameterize it by entering physical and operating data into predefined forms. Models are readily transportable to another simulator or to an engineer's workstation for engineering analysis.

Instructor functions A full set of instructor functions is embedded in the real-time executive program that accompanies each simulation model. Instructor functions are controlled from one PC in the system. For engineering analyses, this instructor's station also serves as an engineering workstation, where the user can set up and review runs.

The compact simulator includes the following instructor functions:

- Selection of unit models
- Real-time, fast, and slow execution
- Selection of initial conditions
- Startup and stopping of a model
- Freezing of model execution
- Taking snapshots
- Backtracking to an earlier point
- Replaying from an earlier point
- Logging and review of trainee actions
- Preparation of plots
- Creation, editing, and initiation of malfunctions
- Creation, editing, and running of preprogrammed transients

One of the most important instructor functions is the ability to edit malfunctions. The system prompts the instructor for a description of the malfunction, the type of component, the component identification, and the failure mode. Each type of component has predefined failure modes. After developing a library of malfunctions, the instructor can initiate single or multiple malfunctions with predefined keystrokes or at predefined times.

Operator interface The trainee interface for a compact simulator can be implemented with a single monitor or with multiple monitors, as shown in the Figure 1 photograph. The graphic screen editor is used to build PC graphic screens that emulate control system hard panels (e.g., the trainee monitor on the left in Figure 1) and display screens (e.g., the trainee monitor on the right). With the editor, a draftsperson or engineering technician can expeditiously build screens and link them to a simulation model. A typical screen requires one day of effort; the most complex screens require two days of effort. The ability to edit screens to accommodate new or revised control system displays is an important feature.

Compact simulator technology also includes interfaces for custom keyboards, thereby allowing the use of vendor-specific keyboards. And the system can easily accommodate a touch screen or some other point device, such as a mouse, trackball, or light pen.

Conclusion

The development of compact simulator technology is an important step toward the objective of expanding and enhancing simulator-based training and technology transfer in the fossil generation industry (GS-6672). By increasing the knowledge and effectiveness of plant operators and by providing control engineers with better analysis tools, compact simulator technology can help utilities reduce O&M and capital costs. In addition, it will be used in developing, testing, and demonstrating new EPRI technologies suitable for fossil plant control room applications. These include integrated performance and diagnostic monitoring systems, retrofit control design features, and human factors guidelines.

For more information about compact simulator technology or the upcoming host utility group meeting, contact Roy Fray at (415) 855-2441.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Residential Demand Ventilation Control (RP2034-44)	$75,000 6 months	Honeywell/*J. Kesselring*
Commercial Building Energy Management System Information Directory (RP2830-10)	$72,800 5 months	Plexus Research/ *L. Carmichael*
Zero-Ozone-Depletion-Potential Refrigerant for Centrifugal Chillers (RP2891-15)	$484,400 36 months	Allied Signal/*W. Krill*
PEAC Power Electronics Program (RP3088-5)	$247,200 4 months	Tennessee Center for Research and Development/*W. Malcolm*
Customer 20/20: Scenario Planning Services (RP3165-10)	$196,500 9 months	Global Business Network/ *M. Evans*
End-Use EMF (RP3254-1)	$180,400 5 months	Tennessee Center for Research and Development/*M. Samotyj*
Electrical Systems		
Effects of Changes in Governor Response on the Security of North American Interconnections (RP2473-53)	$100,000 9 months	Epic Engineering/ *G. Cauley*
FACTS: Evaluation of Thyristor-Controlled Series Compensation for the Minnesota-Manitoba Transmission Upgrade (RP3022-16)	$287,800 12 months	Northern States Power Co./*M. Lauby*
Investigation of S_2F_{10} for Production and Mitigation in Compressed SF_6–Insulated Power Systems (RP3178-3)	$435,200 36 months	Ontario Hydro/*G. Addis*
Improved Pole Treatment Through Use of Supercritical Fluids (RP3238-1)	$781,500 32 months	Oregon State University/ *H. Ng*
Environment		
DNA Adducts and Oxidative DNA Damage as Biological Dosimeters (RP2963-7)	$96,800 11 months	University of North Carolina/*L. Goldstein*
Acute Studies of Acid Aerosols in Children (RP3009-5)	$623,800 12 months	Harvard University/ *J. Yager*
Exploratory and Applied Research		
Steam Methane Reforming in a Porous Ceramic Membrane (RP8003-29)	$55,000 4 months	University of Southern California/*A. Cohn*
Evaluation of Lumeloid™ Concept (RP8007-12)	$100,000 17 months	Advanced Research Development/*T. Peterson*
Application of Artificial Neural Networks in Multiarea Generation Scheduling With Fuzzy Data (RP8010-24)	$59,500 12 months	Illinois Institute of Technology/*R. Adapa*
Iron Deficiency in Marine Phytoplankton (RP8011-9)	$310,600 35 months	Woods Hole Oceanographic Institution/*D. Porcella*
Control Room Crew Operations Research (RP8013-4)	$197,400 17 months	Halliburton NUS Environmental Corp./ *D. Worledge*
Development of Oxygen and pH Sensors for Aqueous Systems (RP9000-9)	$90,700 13 months	University of Notre Dame/ *B. Dooley*
Generation and Storage		
Study of Erosion and Corrosion of Refractories in Circulating-Fluid-Bed Combustors (RP979-30)	$129,700 11 months	Lawrence Berkeley Laboratory/*W. Bakker*
Development of the Bearing Troubleshooting Advisor Workstation (RP1648-13)	$96,700 11 months	Automation Technology/ *T. McCloskey*
Thin-Film Mixed Conductive Membranes for Oxygen Separation (RP1676-16)	$103,200 204 months	Gas Research Institute/ *R. Goldstein*
Commercialization of the Harmonic Impedance Spectroscopy Monitor (RP1893-16)	$226,500 19 months	Cortest Columbus/ *B. Syrett*
Demonstration of Life Assessment Techniques for Boiler Superheater/Reheater Pressure Parts (RP2253-13)	$332,600 22 months	Foster Wheeler Development Corp./ *R. Viswanathan*
Compressed-Air Energy Storage Plant Siting in the Florida Peninsula: Preliminary Investigation (RP2615-16)	$58,800 7 months	ANR Storage/*B. Mehta*
Extension of BLADE Code for Analysis of Combustion Turbine Blades (RP2775-10)	$239,400 12 months	Stress Technology/*J. Allen*
Value Engineering Analysis of CAES Demonstration Plant (RP2894-12)	$199,000 17 months	Energy Storage & Power Consultants/ *R. Pollak*
Demonstration of Coal Reburning for Cyclone Boiler NO_x Control (RP2916-15)	$1,000,000 44 months	Babcock & Wilcox Co./ *A. Kokkinos*
Extreme Rainfall Probability (RP2917-33)	$161,100 13 months	Yankee Atomic Electric Co./*D. Morris*
Assessment of Compressed-Air Energy Storage Sites in the TVA Service Area (RP3049-4)	$245,000 13 months	Tennessee Valley Authority/*B. Mehta*
Fossil Plant Simulation and Technical Support (RP3152-8)	$145,200 15 months	American Systems Engineering Corp./ *M. Divakaruni*
Nuclear Power		
Sourcebook for Bivalve Macrofouling in Nuclear and Fossil Fuel Power Stations (RP2495-16)	$127,100 21 months	University of Texas, Arlington/*N. Hirota*
Severe-Accident Activities Support (RP2636-11)	$75,400 10 months	Altos Engineering Applications/*A. Machiels*
Framework for Alternate Modes Probabilistic Risk Assessment (RP3333-3)	$89,700 8 months	PLG, Inc./*J. Sursock*
Framework for Alternate Modes Probabilistic Risk Assessment (RP3333-4)	$86,000 8 months	Erin Engineering and Research/*J. Sursock*
Motor-Operated Valve Performance Prediction Program: Quality Assurance Support (RP3433-9)	$158,300 34 months	S. Levy, Inc./*J. Hosler*
Influence of Roughness on Mass Transfer (RP3500-4)	$56,400 12 months	NEI International R&D Co./*B. Chexal*
Hydrogen Water Chemistry Interruption Study (RPC101-19)	$244,000 11 months	General Electric Co./ *L. Nelson*
Prediction of Electrochemical Potentials in BWRs (RPC101-20)	$199,900 20 months	General Electric Co./ *R. Pathania*
Examination of Attachment Welds, Cladded Vessels, and MSIP Remedies (RPC105-7)	$169,100 5 months	J. A. Jones Applied Research Co./*S. Liu*
Acid/Base Titrations in High-Temperature Aqueous Solutions (RPS407-45)	$114,100 23 months	Pennsylvania State University/*P. Millett*
Ginna Station Steam Generator U-Bend Tube Analysis for Chemical Cleaning Data (RPS413-1)	$336,900 9 months	Babcock & Wilcox Co./ *L. Williams*
Examination of Trojan Steam Generator Tubes (RPS413-2)	$224,400 7 months	Combustion Engineering/ *A. McIlree*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Dr., P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. 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 pay the listed price. The Distribution 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

Saving Energy and Reducing CO_2 With Electricity: Estimates of Potential
CU-7440 Final Report (RP2788); $200
Contractor: Zaininger Engineering Co., Inc.
EPRI Project Manager: T. Yau

Applications of Compressor Capacity Modulation in the Industrial and Commercial Sectors
TR-100035 Final Report (RP2224-3); $200
Contractor: Applied Energy Systems, Inc.
EPRI Project Manager: P. Meagher

Integrating Demand-Side Management Programs Into the Resource Plans of U.S. Electric Utilities
TR-100255 Final Report (RP2982-8); $200
Contractor: Oak Ridge National Laboratory
EPRI Project Manager: P. Hanser

Customer Systems Division: Strategic Overview
TR-100350 Special Report; $200
EPRI Project Manager: C. Gellings

ELECTRICAL SYSTEMS

TLWorkstation™ Code, Version 2.0, Vols. 13 and 14: UPSTUDY/TLOPGR Manual
EL-6420 Final Report (RP2151-1); $200
Contractor: Power Technologies, Inc.
EPRI Project Manager: R. Kennon

Advanced Digital Line Protection Relay
EL-7403 Final Report (RP1359-17); $200
Contractor: General Electric Co.
EPRI Project Manager: L. Mankoff

Waltz Mill Testing of 345-kV PPP Cable
EL-7429 Final Report (RP7801-7); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Shimshock

Round-Robin Test on CIGRE Water Tree Resistance Evaluation Methods for Extruded Cable Insulation, Vol. 1: Phase 1
EL-7432 Final Report (RP2957-1); $200
Contractor: University of Connecticut
EPRI Project Manager: B. Bernstein

Pilot Study of Nonresidential Power Frequency Magnetic Fields
EL-7452 Final Report (RP2942-6); $495
Contractor: General Electric Co.
EPRI Project Manager: G. Rauch

Far-Infrared Cable Inspection Laser
EL-7455 Final Report (RP794-7); $200
Contractor: Georgia Power Co., Southern Electric International Research Center
EPRI Project Manager: J. Porter

Pellet Detector Investigation
EL-7478 Final Report (RP2479-1); $200
Contractor: BICC Cables Corp.
EPRI Project Manager: J. Porter

Light Metal Hydrides and Superconductivity
EL-7507 Final Report (RP7911-3); $200
Contractor: Purdue University
EPRI Project Manager: M. Rabinowitz

ENVIRONMENT

High-Resolution Electromagnetic Imaging of Subsurface Contaminant Plumes
EN-7519 Interim Report (RP2485-11); $200
Contractor: University of Arizona, Tucson
EPRI Project Manager: D. McIntosh

EXPLORATORY AND APPLIED RESEARCH

Physicochemical Principles of Coal-Water-Slurry Gasifier Feedstock
EAR/GS-7467 Final Report (RP8006-6); $200
Contractor: Adelphi University
EPRI Project Manager: B. Weber

Using Pitting and Protection Potentials to Predict Pitting Behavior: New Insights
EAR-7489 Final Report (RP8002-15); $200
Contractor: Cortest Columbus Technologies
EPRI Project Manager: B. Syrett

GENERATION AND STORAGE

High-Temperature Gas Filtration, Vol. 3: Flow Characteristics and Heat Transfer in a Ceramic Filter Element
GS-6489 Final Report (RP1336-7); $200
Contractor: Rheinisch-Westfälische Technische Hochschule Aachen
EPRI Project Manager: O. Tassicker

Biomass State-of-the-Art Assessment, Vols. 1 and 2
GS-7471 Final Report (RP2612-13); $200 each volume
Contractor: Research Triangle Institute
EPRI Project Manager: J. Berning

Proceedings: 1991 Second International Symposium on the Biological Processing of Coal
GS-7482 Proceedings; $200
EPRI Project Manager: S. Yunker

Colorado-Ute Nucla Station Circulating-Fluidized-Bed Demonstration, Vol. 1: Test Program Preparation
GS-7483 Final Report (RP2683-7); $200
Contractor: Bechtel Group, Inc.
EPRI Project Manager: T. Boyd

Improving Existing Gas Turbine Reliability: Putnam Plant Demonstration
GS-7490 Final Report (RP2989-1); $200
Contractor: PLG
EPRI Project Manager: R. Frischmuth

Preliminary Design of Coal-Fired Supercritical Sliding-Pressure Boilers for Turbine Steam Conditions of 4500 psi, 1100°F
GS-7521 Interim Report (RP1403-14); $200
Contractors: ABB Combustion Engineering Systems; Sulzer Brothers, Ltd.
EPRI Project Manager: W. Bakker

Miniature Specimen Test Technique for Estimating Toughness
GS-7526 Final Report (RP1957-10); $500
Contractor: Failure Analysis Associates, Inc.
EPRI Project Manager: R. Viswanathan

Groundwater Manual for the Electric Utility Industry, Second Edition, Vol. 1: Groundwater Laws, Geologic Formations, and Groundwater Aquifers
GS-7534 Final Report (RP2301-1); $200
Contractor: Southern Company Services, Inc.
EPRI Project Manager: D. Golden

Decision Advisor for Aging Components: A Feasibility Study
GS/EN-7536 Final Report (RP2308-19); $200
Contractor: Strategic Decisions Group
EPRI Project Managers: B. Dooley, M. Divakaruni, T. Wilson

Proceedings: 1991 Conference on Waste Tires as a Utility Fuel
GS-7538 Proceedings; $200
EPRI Project Manager: C. McGowin

Multisystem Corrosion Monitoring in a Condensing Flue Gas Heat Exchanger: Phase 2
GS-7540 Final Report (RP1871-17); $200
Contractor: CAPCIS-MARCH, Ltd.
EPRI Project Manager: B. Syrett

Assessment of Selected Technologies for Remediation of Manufactured Gas Plant Sites
GS-7554 Final Report (RP3072-1); $200
Contractor: IT Corp.
EPRI Project Managers: M. McLearn, B. Nott, T. Lott

Monitoring Cycle Water Chemistry in Fossil Plants, Vols. 1–3
GS-7556 Final Report (RP2712-3); Vol. 1, $200; Vol. 2, forthcoming; Vol. 3, $200
Contractor: Sargent & Lundy
EPRI Project Manager: B. Dooley

INTEGRATED ENERGY SYSTEMS

Coal Transportation Risks for Fuel Switching Decisions, Vol. 1: Powder River Basin and Inland Waterways
IE-7118 Final Report (RP3199-4); $200
Contractor: Fieldston Co., Inc.
EPRI Project Manager: J. Platt

A Framework for Strategic Cost Management
P-7242 Final Report (RP3206-1); $200
Contractor: Strategic Decisions Group
EPRI Project Managers: E. Altouney, H. Mueller

NUCLEAR POWER

A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1)
NP-6041-M Final Report (RP2722-23); $200
Contractors: Jack Benjamin and Associates, Inc.; RPK Structural Mechanics Consulting; Pickard, Lowe and Garrick; I. M. Idriss; Southern Company Services, Inc.
EPRI Project Manager: R. Kassawara

Transport of Lead in PWR Secondary Cycles
NP-7158 Final Report (RPS401-2); $25
Contractor: NWT Corp.
EPRI Project Manager: P. Paine

Predictive Maintenance Primer
NP-7205 Final Report (RP2814-22); $7500
Contractor: NUS Corp.
EPRI Project Manager: M. Downs

Prairie Island–2 Steam Generator Hideout
NP-7236 Interim Report (RPS401-1); $200
Contractor: NWT Corp.
EPRI Project Managers: C. Welty, P. Millett

Treatment of Radioactive Ion-Exchange Resins: Low-Temperature Resin Oxidation Process
NP-7368-M Final Report (RP1329-5, RP2296-23); $200
NP-7368-S Final Report; $5000
Contractors: EPRI Nondestructive Evaluation Center; Bradtec, Ltd.; LN Technologies Corp.; Quadrex Corp.
EPRI Project Manager: C. Wood

Guidelines for Design of PWR Steam Generator Chemical Cleaning Systems
NP-7384 Final Report (RPS307-13); $200
Contractors: GEBCO Engineering, Inc.; Dominion Engineering, Inc.
EPRI Project Manager: C. Welty

Guidelines for Soil-Structure Interaction Analysis
NP-7395 Final Report (RP2225-9); $200
Contractor: Bechtel Group, Inc.
EPRI Project Manager: Y. Tang

Effect of Lithium Hydroxide on Primary Water Stress Corrosion Cracking of Alloy 600 Tubing
NP-7396-M Final Report (RP2648-1); $200
NP-7396-S Final Report; $5000
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: C. Wood

Breaker Maintenance, Vol. 3: Molded-Case Circuit Breakers
NP-7410 Final Report (RP2814-38); $8000
Contractor: Edan Engineering Corp.
EPRI Project Manager: J. Christie

RAYTRACE: Computer-Aided Ultrasonic Plotting Tool
NP-7448-M Final Report (RP1570-2); $200
Contractor: J. A. Jones Applied Research Co.
EPRI Project Managers: S. Liu, M. Avioli

Survey of Utility Robotic Applications (1990)
NP-7456 Special Report (RP2232); $200
Contractor: Utility/Manufacturers Robot Users Group
EPRI Project Manager: M. Lapides

BWR Water Chemistry Impurity Studies, Phase 2: Executive Summary
NP-7458-M Interim Report (RP2293-1); $200
Contractor: ABB Atom AB
EPRI Project Manager: D. Cubicciotti

Conceptual Design for an On-Site Spent-Fuel Transfer System
NP-7459 Final Report (RP2813-25); $200
Contractor: Transnuclear, Inc.
EPRI Project Manager: R. Lambert

Treatment, Packaging, and Storage of Bundle Scrap Hardware
NP-7463 Final Report (RP2813-13); $200
Contractor: Rochester Gas and Electric Corp.
EPRI Project Manager: R. Lambert

Nondestructive Evaluation Sourcebook
NP-7466-M Final Report (RP1570-32); $200
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: S. Liu

Electrochemical Studies of Microbiologically Influenced Corrosion
NP-7468 Final Report (RP2939-5); $200
Contractor: University of Tennessee, Knoxville
EPRI Project Manager: D. Cubicciotti

Residual Stress Analysis in Reactor Pressure Vessel Attachments: Review of Available Welding Simulation Software
NP-7469 Interim Report (RPC102-3); $2500
Contractor: Southwest Research Institute
EPRI Project Manager: M. Behravesh

Microstructure and Nodular Corrosion of Zircaloy-2
NP-7470 Final Report (RP1250-16); $200
Contractor: General Electric Co.
EPRI Project Managers: H. Ocken, R. Yang

Evaluation of Flaws in Ferritic Piping: ASME Code Appendix J, Deformation Plasticity Failure Assessment Diagram (DPFAD)
NP-7492 Final Report (RP1757-34); $200
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: S. Tagart

Statistical Analysis of Steam Generator Tube Degradation
NP-7493 Final Report (RPS405-9); $200
Contractor: Dominion Engineering, Inc.
EPRI Project Managers: C. Welty, P. Paine

Hideout and Return of Complex Mixtures in Crevices
NP-7494 Final Report (RPS407-13); $200
Contractor: Atomic Energy of Canada, Ltd.
EPRI Project Managers: P. Paine, P. Millett

Modeling of Molten Core–Concrete Interactions and Fission-Product Release
NP-7495 Interim Report (RP2636-5); $200
Contractor: University of Wisconsin, Madison
EPRI Project Manager: B. Sehgal

Hot Cell Examination of Oconee–2 Fuel Rods
NP-7499-M Final Report (RP2229-7); $200
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: H. Ocken

The October 17, 1989, Loma Prieta Earthquake: Effects on Selected Power and Industrial Facilities
NP-7500-M Final Report (RP2848-6); $200
Contractors: EQE Engineering, Inc.; Precision Measurement Instruments
EPRI Project Manager: R. Kassawara

CALENDAR

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

APRIL

6–10
Workshop: BLADE Software
Rochester, New York
Contact: Tom McCloskey, (415) 855-2655

8
Advanced Heat Pump Interest Group Meeting
Location to be determined
Contact: Dave Ross, (703) 742-8402

8–9
Efficiency Maintenance Analysis Program Workshop and Users Group Meeting
Charlotte, North Carolina
Contact: David Dobbins, (704) 547-6162

8–9
Key Account Marketing With CLASSIFY-Plus: A Training Workshop for Utility Field Reps
Minneapolis, Minnesota
Contact: Thom Henneberger, (415) 855-2885

8–10
Training Workshop: COMTECH and COOLAID Software
San Diego, California
Contact: Karl Johnson, (415) 855-2183

9
Asbestos Control and Replacement for Utilities
Pittsburgh, Pennsylvania
Contact: Linda Nelson, (415) 855-2127

14–15
Conference: Fossil Plant Layup and Reactivation
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

21–24
5th International Workshop on Main Coolant Pumps
Orlando, Florida
Contact: Jean Carpenter, (704) 547-6141

22–23
Conference: Industrial Energy Technology
Houston, Texas
Contact: Ammi Amarnath, (415) 855-2548

22–24
Seminar: Corrosion in Power Plant Service Water Systems
Clearwater, Florida
Contact: Bob Edwards, (415) 855-8974

27–28
Training Workshop: REEPS 2.0 Software
Dallas, Texas
Contact: Phil Hummel, (415) 855-2855

29–30
Training Workshop: COMMEND Software
Dallas, Texas
Contact: Phil Hummel, (415) 855-2855

30–May 1
Training Workshop: Measurement of Power System Magnetic Fields
Lenox, Massachusetts
Contact: John Dunlap, (415) 855-2298

MAY

4–5
Training Workshop: HELM-PC 1.0 Software
Dallas, Texas
Contact: Phil Hummel, (415) 855-2855

5–6
Seminar: Electrotechnology Training
St. Louis, Missouri
Contact: Patrick McDonough, (415) 855-2714

5–7
Seminar: Power Plant Reliability and Availability Analysis Using the UNIRAM Method and the GADSRAM Data Bridge
St. Louis, Missouri
Contact: Jerome Weiss, (415) 855-2495

5–8
Generator Monitoring and Diagnostics
Eddystone, Pennsylvania
Contact: Murthy Divakaruni, (415) 855-2409

6–7
HELM-PC Software Users Group Meeting
Dallas, Texas
Contact: Phil Hummel, (415) 855-2855

7–8
Affiliate Member Program (AMP) Conference
St. Louis, Missouri
Contact: Marsha Grossman, (415) 855-2899

13–15
NMAC Workshop: Solenoid Valve Maintenance
Philadelphia, Pennsylvania
Contact: Vic Varma, (704) 547-6056

18–20
Conference: Flexible AC Transmission Systems (FACTS)
Boston, Massachusetts
Contact: Ben Damsky, (415) 855-2385

26–29
NDE Workshop: Balance-of-Plant Heat Exchangers
Key West, Florida
Contact: Kenji Krzyowsz, (704) 547-6096

31–June 4
International Conference: Mercury as a Global Pollutant
Monterey, California
Contact: Pam Turner, (415) 855-2010

JUNE

1–3
International Conference: Controls and Instrumentation
Kansas City, Missouri
Contact: Lori Adams, (415) 855-8763

3–5
International Conference: Interaction of Iron-Based Materials With Water and Steam
Heidelberg, Germany
Contact: Barry Dooley, (415) 855-2458

8–12
Seminar: HV Transmission Line Design
Lenox, Massachusetts
Contact: Dick Sigley, (518) 385-2222

9–11
Acoustic Leak and Crack Detection
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

16–18
Workshop: Heat Exchanger Performance Prediction
Eddystone, Pennsylvania
Contact: John Tsou, (415) 855-2220

25–26
Outage Risk Assessment Management
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

JULY

6–9
1992 Meeting on Electric Thermal Storage and Thermal Energy Storage
Minneapolis, Minnesota
Contact: Linda Nelson, (415) 855-2127

7–9
2d International Conference on CAES
San Francisco, California
Contact: Lori Adams, (415) 855-8763

7–9
International Conference: Electric Thermal Storage and Thermal Energy Storage
Minneapolis, Minnesota
Contact: David Ross, (703) 742-8402

7–9
Workshop: NO_x Controls for Utility Boilers
Boston, Massachusetts
Contact: Pam Turner, (415) 855-2010

14–17
Machinery Alignment
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

20–22
Training Workshop: COMTECH and COOLAID Software
Dallas, Texas
Contact: Karl Johnson, (415) 855-2183

21–23
Predictive Maintenance Program: Development and Implementation
Eddystone, Pennsylvania
Contact: Mike Robinson, (215) 595-8876

23–24
Training Workshop: micro-AXCESS Software
Dallas, Texas
Contact: Karl Johnson, (415) 855-2183

28–29
FGDPRISM Training Workshop
Dallas, Texas
Contact: Rob Moser, (415) 855-2277

AUGUST

3–6
Check Valve Applications, Maintenance, Monitoring, and Diagnostics
Eddystone, Pennsylvania
Contact: Joe Weiss, (415) 855-2751

25–26
Workshop: Optical Sensing in Utility Applications
Philadelphia, Pennsylvania
Contact: Jan Stein, (415) 855-2390

25–27
3d International Conference: Effects of Coal Quality on Power Plants
San Diego, California
Contact: Arun Mehta, (415) 855-2895

SEPTEMBER

13–16
International Conference: Avian Interactions With Utility Structures
Miami, Florida
Contact: John Huckabee, (415) 855-2589

17–18
Training Workshop: Measurement of Power System Magnetic Fields
Lenox, Massachusetts
Contact: Hazel Mazza, (413) 494-4356

21–23
5th Incipient Failure Detection Conference
Knoxville, Tennessee
Contact: Dave Broske, (415) 855-8968

28–30
Conference: Power Quality—End-Use Applications and Perspectives
Atlanta, Georgia
Contact: Marek Samotyj, (415) 855-2980

OCTOBER

14–16
Symposium: Feedwater Heater Technology
Birmingham, Alabama
Contact: John Tsou, (415) 855-2220

21–23
National Electric Vehicle Conference
San Francisco, California
Contact: Jim Janasik, (415) 855-2486

29–30
FGDPRISM Training Workshop
Dallas, Texas
Contact: Rob Moser, (415) 855-2277

NOVEMBER

17–19
AIRPOL '92 International Seminar: Solving Corrosion Problems in Air Pollution Control Equipment
Orlando, Florida
Contact: Paul Radcliffe, (415) 855-2720

17–19
Heat Rate Improvement Conference
Birmingham, Alabama
Contact: Bob Leyse, (415) 855-2995

DECEMBER

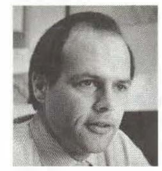
2–4
Seminar: Noncombustion Waste
Orlando, Florida
Contact: Mary McLearn, (415) 855-2487

Authors and Articles


Sagan

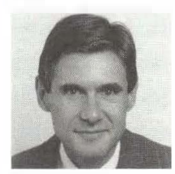

Sussman


Kheifets


Black


Barker


Jeffress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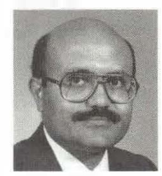
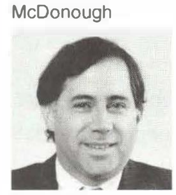

Amarnath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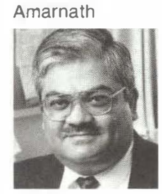
Bhatt

Sharpening the Focus in EMF Research (page 4) was written by Taylor Moore, the *Journal*'s senior feature writer, with guidance from several members of EPRI's Environment Division.

Leonard Sagan, senior medical scientist, was formerly program manager for radiation studies, which included EPRI's research into the health effects of exposure to electric and magnetic fields (EMF). Sagan came to EPRI in 1978 after working as a clinical director of environmental medicine. He has also conducted research in nuclear medicine for the former Atomic

(continued next page)

(Authors and Articles continued)

Energy Commission. Sagan earned an MD at the University of Chicago and an MPH at the Harvard School of Public Health.

Stanley Sussman, manager of the renamed EMF Health Studies Program, joined EPRI in 1987 as a project manager for EMF exposure assessment studies. A physicist, Sussman previously worked for five years in instrumentation development and, earlier, managed research in systems modeling. Sussman has an MS from Stevens Institute of Technology and a PhD in physics from City College of New York.

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

Robert Black, also an epidemiologist, has been a project manager in EMF studies since 1979. Black came to EPRI from the University of Texas School of Public Health, where he earned an MPH. He earlier worked as field program manager for Amigos de las Américas, an international public health program. ■

Energy Efficiency: Probing the Limits, Expanding the Options (page 14) was written by **Brent Barker** from information presented at the most recent EPRI Summer Seminar.

Barker is currently EPRI's manager of corporate information, having earlier served for 12 years as editor in chief of the *EPRI Journal*. Before joining the Institute in 1977, he spent four years as a private communications consultant and as an analyst for URSA, an economics consulting firm. Barker also worked as an industrial economist and staff author at SRI International and as a commercial research analyst at USX Corporation. He graduated in engineering science from Johns Hopkins and earned an MBA at the University of Pittsburgh. ■

Technology for More Profitable Recycling (page 22) was written by Leslie Lamarre, *Journal* feature writer, with assistance from three members of the Customer Systems Division.

Bob Jeffress, manager of the Industrial Program, joined EPRI in 1986. Before that he spent 13 years with the American Iron and Steel Institute in Washington, D.C., including 5 years as director of technology with responsibility for collaborative R&D, university research, and industry manufacturing committees. His previous experience includes 10 years as a manager with Armco Steel Corporation. He has a BS degree in metallurgical engineering from Purdue University.

Pat McDonough joined EPRI last year as manager of the Industrial Program's materials production and fabrication work. He was previously chief financial officer for several San Francisco Bay Area high-technology startup companies and was a division controller for Memorex. Earlier he worked for McKinsey & Company as a management consultant and held engineering positions with the Lummus Company. McDonough received a BS in chemical engineering from Rice University and an MBA from Stanford.

Ammi Amarnath, a senior project manager in the Industrial Program, manages research on electrotechnologies for process industries. He joined EPRI in 1988, following seven years as a process engineer and supervisor for two manufacturers of process equipment, K-Sons Ltd. and Metito International. Amarnath has BS and MS degrees in chemical engineering from the University of Mysore (India) and the University of California at Santa Barbara, respectively. He also received an MBA from the University of Houston. ■

Young Investigators Leverage Research Power (page 30) was written by Michael Scofield, science writer, with assistance from two EPRI staff members.

Tom Schneider, executive scientist, comanages the Office of Exploratory and Applied Research. Among other duties, he directs programs in the physical and mathematical sciences. Schneider joined EPRI in 1977, following four years with Public Service Electric & Gas in New Jersey. From 1981 to 1985, he was director of the Energy Utilization and Technology Department. After that he was on loan to the Lighting Research Institute for two years, serving as president. He has a BS degree from Stevens Institute of Technology and a PhD in physics from the University of Pennsylvania.

Siddharth Bhatt is a senior project manager in the Control and Diagnosis Program of the Nuclear Power Division, with primary responsibility for intelligent digital systems for control and automation. Before joining EPRI in 1989, he managed R&D projects for Litton Industries' Applied Technology Division for two years. His earlier experience includes 13 years with General Electric Company's Nuclear Energy Business Operation. He has a master's degree in nuclear engineering and a PhD in physics from Rensselaer Polytechnic Institute. ■

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