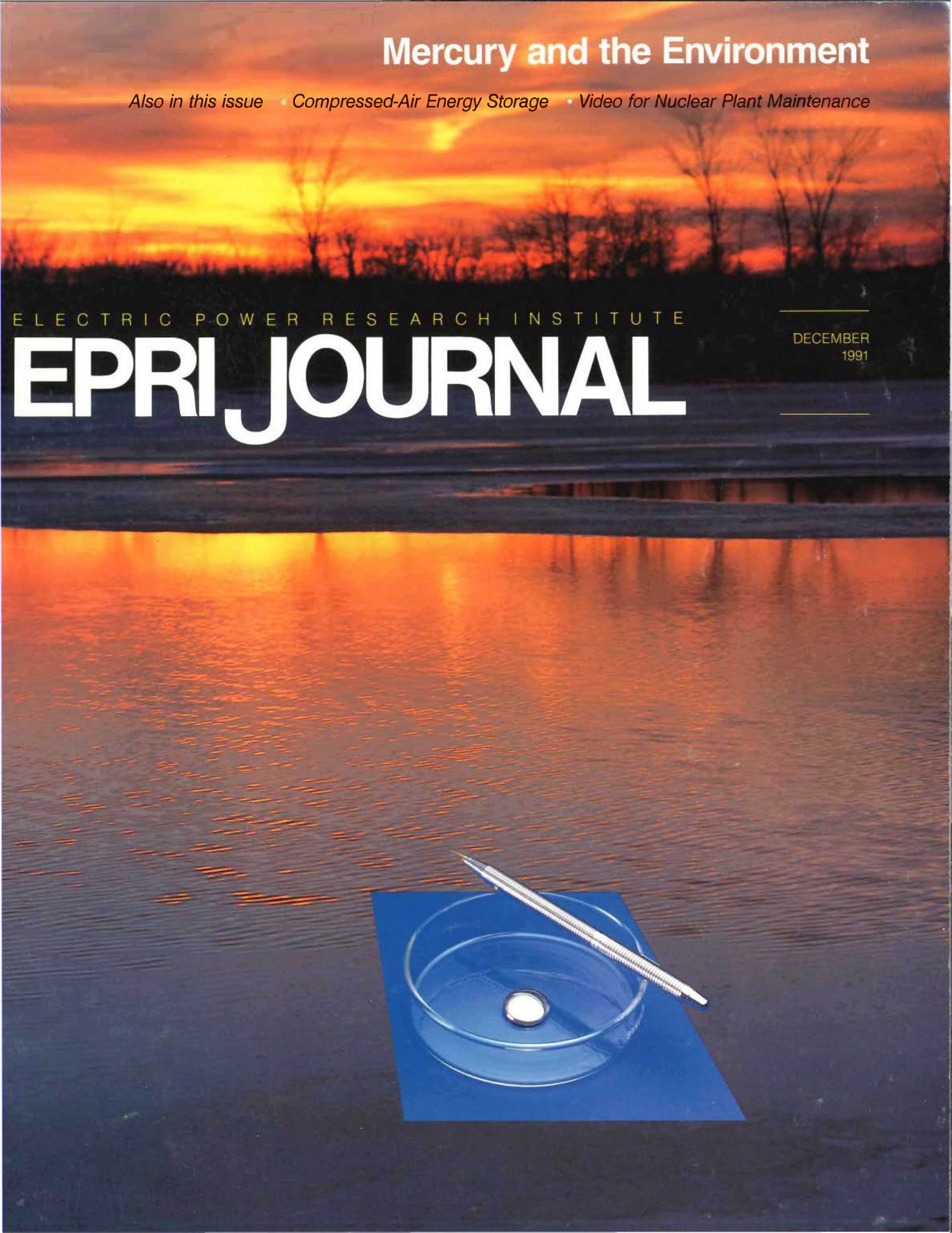
Mercury and the Environment

Also in this issue · *Compressed-Air Energy Storage* · *Video for Nuclear Plant Maintenance*

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

DECEMBER
1991



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

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

EPRI JOURNAL Staff and Contributors
David Dietrich, Editor
Taylor Moore, Senior Feature Writer
Leslie Lamarre, Feature Writer
Susan Dolder, Technical Editor
Mary Ann Garneau, Senior Production Editor
Jean Smith, Staff Assistant

Brent Barker, Manager
Corporate Information

Richard G. Claeys, Director
Corporate Communications Division

Graphics Consultant: Frank A. Rodriquez

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

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

Cover: A gram of atmospheric mercury, deposited in a remote lake and changed to toxic forms through in-lake processes, may contaminate large fish to the degree that eating them poses a significant health risk to humans and other animals.

The Mercury Challenge

Since ancient times, mercury has been one of the most useful metallic elements. Current applications range from batteries to thermometers, from fluorescent lamps to fungicides. Health hazards associated with mercury have also long been recognized. It does not contribute to any known body function, is difficult to excrete, builds up in food chains, and—in sufficient quantities—can damage the central nervous system. Now, surprising levels of mercury have been discovered in fish from remote lakes that lie far from industrial activity.

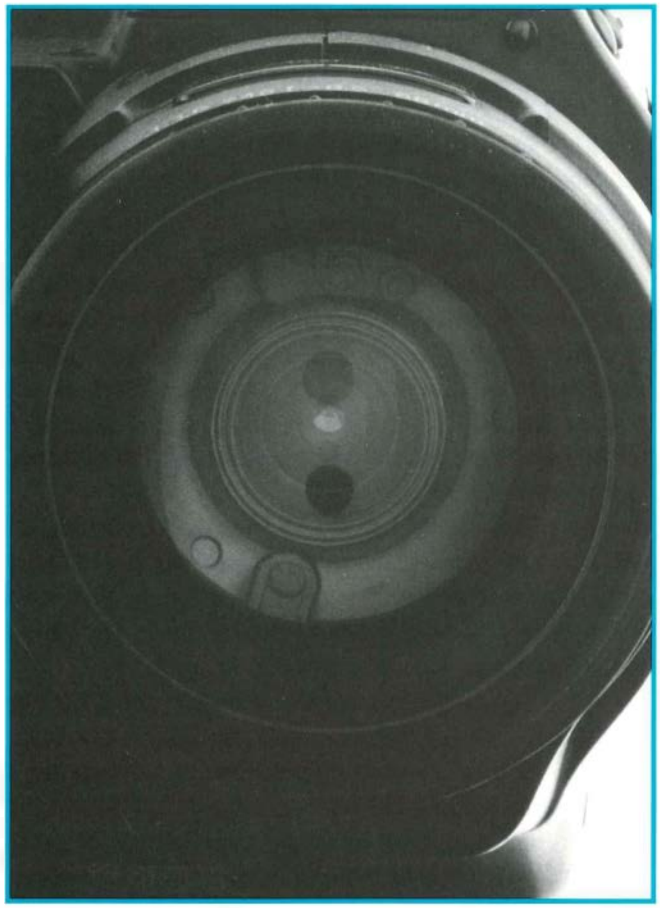
Atmospheric deposition of mercury is the suspected cause, which raises a challenge for electric utilities, since burning coal results in some mercury emissions to the air. Although the contribution of U.S. electric utilities to the global atmospheric burden of mercury is quite small—probably less than 3%—our need to investigate the problem is high because in the 1990 Clean Air Act Amendments, Congress has requested evaluation of the efficacy of regulating emissions. Through EPRI, the utility industry can play a major role in clarifying how mercury enters and moves through the environment, in assessing risks to human health and ecological systems, and in determining what mitigation strategies might prove most effective.

This month's cover story focuses on a particularly timely aspect of this work—the atmospheric deposition of mercury into remote lakes and its subsequent cycling through the aquatic ecosystem. As the article emphasizes, this research is fraught with technical difficulties. Some previous sampling efforts produced estimates of mercury levels in lakes that were 500-fold too high, owing to sample contamination during collection and analysis.

By using exceptionally clean sampling techniques, researchers have now produced the first precise estimates of mercury mass distribution in remote lakes. Among their important conclusions: The quantities of mercury entering the water by atmospheric deposition are very small, but they do, indeed, appear to be sufficient to account for contamination of the food chain in some of these lakes. Although utility emissions account for only a small fraction of the deposition, efforts to understand the role of these emissions in the overall cycle of mercury in the environment clearly deserve our continuing support.

Stephen C. Peck, Director
Environment Division

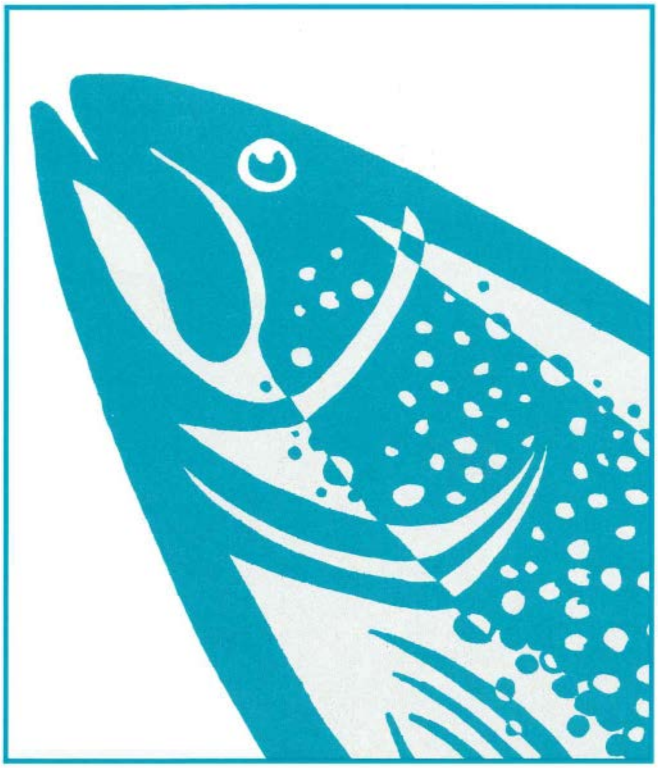
RESEARCH UPDATE



DEPARTMENTS

EPRI JOURNAL

Volume 16, Number 8 December 1991



4 Mercury

12 Compressed-Air Energy Storage

It's a problem we thought had gone away. After more than a hundred people in Minimata, Japan, died from eating fish contaminated by a methyl mercury discharge in the mid-1950s, industrialized nations around the world began prohibiting the dumping of mercury into waterways. As a result, the amount of mercury compounds in lakes and rivers receiving these discharges rapidly decreased, and contamination of the food chain hasn't been considered much of a threat to human health in the United States for years. Now, subtly and even somewhat mysteriously, significant levels of mercury have shown up in numerous lakes in the northeastern and north central United States, eastern Canada, and Scandinavia. Many of these lakes are remote from industry and have been called pristine. Yet contamination of the food chain in some lakes is severe enough that public health officials in several states have recently issued warnings against eating the large predatory fish caught in these lakes—such as bass and walleyes—which accumulate the highest levels of mercury.

Although there is no evidence that human health has yet been compromised by the newly discovered mercury contamination, some ecological damage has already apparently occurred. In the Florida Everglades, alligators, bald eagles,

MERCURY IN THE ENVIRONMENT

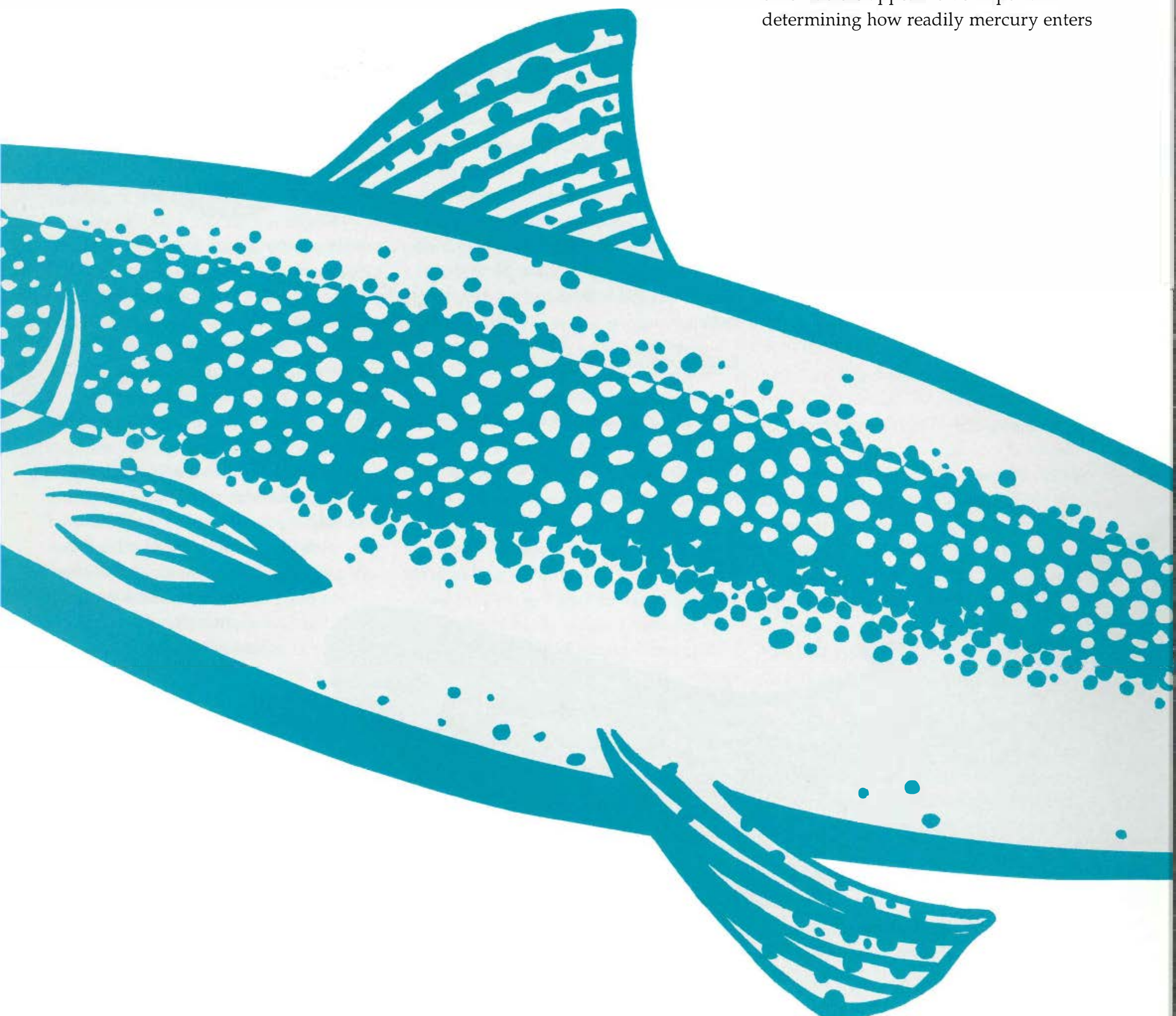
THE STORY IN BRIEF

Researchers have discovered surprisingly high levels of mercury in remote lakes of the northeastern and north central United States—at sites far removed from any point-source industrial facilities. Ingestion and bioaccumulation of mercury in fish can have a substantial effect on the local food chain, including watershed mammals and predatory birds. Research has now shown that the extremely small quantities of atmospheric mercury deposited in lakes are nevertheless large enough to account for the contamination observed. EPRI has pioneered understanding of this issue through state-of-the-art measurement of mercury concentrations in lakes and development of a model of the aquatic mercury cycle that can predict mercury concentrations at various levels of the food chain. Research is also proceeding on ways to detoxify mercury through enhancement of natural demethylation by bacteria already present in contaminated lakes.

and raccoons feeding on contaminated fish have built up highly concentrated levels of mercury, and some panther deaths have been blamed on eating the raccoons. In the Great Lakes region, mercury ingestion is suspected to be the cause of reproductive problems in eagles, otters, minks, and other animals.

Since open dumping of mercury waste and point-source discharges from chemical companies can be ruled out in most cases, atmospheric deposition has been suggested as the primary cause of mercury contamination in seepage lakes—lakes whose water comes mainly from rainfall. In drainage lakes, which have known inlets and outlets such as streams, the most likely source appears to be a combination of atmospheric deposition on the lake and watershed and the weathering of geologic formations. Most of the mercury responsible for contamination in the Everglades is thought to result from agricultural runoff.

Mercury vapor in the atmosphere comes from a variety of natural and artificial sources: releases from the ocean and land surfaces, smelters, power plants, forest fires, mineral deposits, paint volatilization, disposal of batteries and fluorescent lamps, and the application of certain fungicides. In addition, other factors appear to be important in determining how readily mercury enters



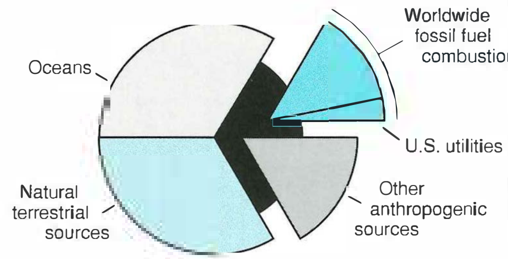
an aquatic food chain. It has been suggested, for example, that acidity may hasten the process, which has raised a further concern: that acid rain could lower the pH of vulnerable lakes and thus exacerbate mercury contamination of the food chain. The potential importance of this effect, however, remains unclear—neither the Everglades nor the pristine lakes of the upper Midwest have been substantially impacted by acid deposition.

Because of the possible contribution of power plant emissions to both mercury deposition and acid rain, EPRI has launched a broad series of investigations into the problem of mercury contamination. A key part of this research is a project on mercury in temperate lakes—the MTL project—which uses the latest analytical techniques to evaluate geologic and atmospheric sources of mercury and to find out which environmental factors determine the rate of mercury concentration in the food chain. This work has led to the first comprehensive set of data showing how mercury is distributed in aquatic systems, as well as to the development of a unique model that simulates the cycling of mercury in lakes.

In addition, EPRI has launched a project called PISCES (Power Plant Integrated Systems: Chemical Emissions Study) to develop a comprehensive assessment methodology that can predict the emission and fate of various toxic substances, including mercury, in fossil plant process streams (*EPRI Journal*, March 1991, p. 4). Information developed from this project will be used to determine potential risks to human health through a new methodology called RiskPISCES. This methodology is specifically designed to help utilities satisfy recent requirements for conducting risk assessments related to air quality standards. Previous risk research on air toxics focused primarily on human exposure due to inhalation; RiskPISCES provides a broader look, including exposure through groundwater, skin contact, and the food chain. Most mercury enters the human body through food.

Exposure of fishermen

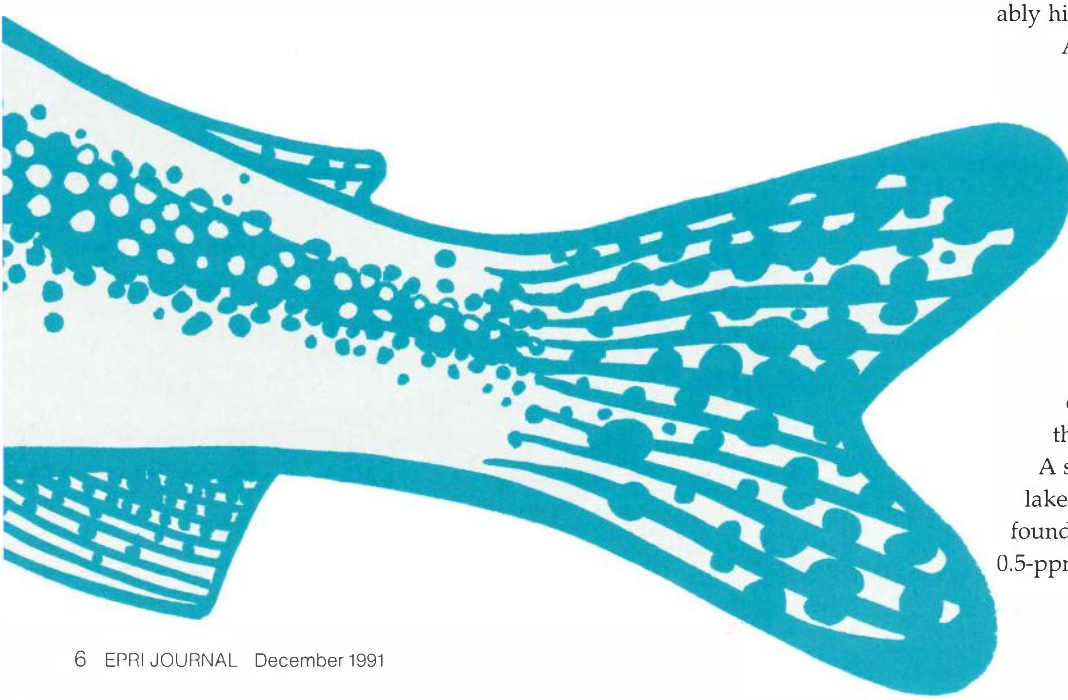
The dangers of human exposure to mercury have long been recognized. Nineteenth-century hat makers, for example, developed a characteristic shaking and slurring of speech from occupational exposure to large quantities of inorganic mercury during the manufacturing process—symptoms that gave rise to the phrase "mad as a hatter." Such problems result from impairment of the central nervous system; in addition, high levels of mercury can cause kidney damage, birth defects, and in extreme cases, as at Minimata, death.



GLOBAL SOURCES FOR AIRBORNE MERCURY **Atmospheric mercury vapor that is eventually deposited in lakes comes from a variety of natural and man-made sources. About a third comes from the oceans, and another third results from natural soil processes, such as outgassing and geologic weathering. Of mercury from anthropogenic sources, about half can be attributed to worldwide fossil fuel combustion; the rest is released through fungicide and paint volatilization, manufacturing processes, and the breakdown of batteries, fluorescent lamps, and other discarded objects. Something less than 3% of the total is believed to come from U.S. electric power generation.**

In the United States today the groups most likely to be exposed to unacceptably high levels of mercury are Native American and recreational fishermen, who routinely eat large amounts of their catch. The U.S. Food and Drug Administration considers a mercury level of 1 part per million (ppm) to be its action level—that is, the recommended upper limit for safe consumption. Several states have even stricter standards, which they use to issue health advisories.

A survey of fish in selected remote lakes on Michigan's upper peninsula found that 15% exceeded that state's 0.5-ppm health advisory level, while in

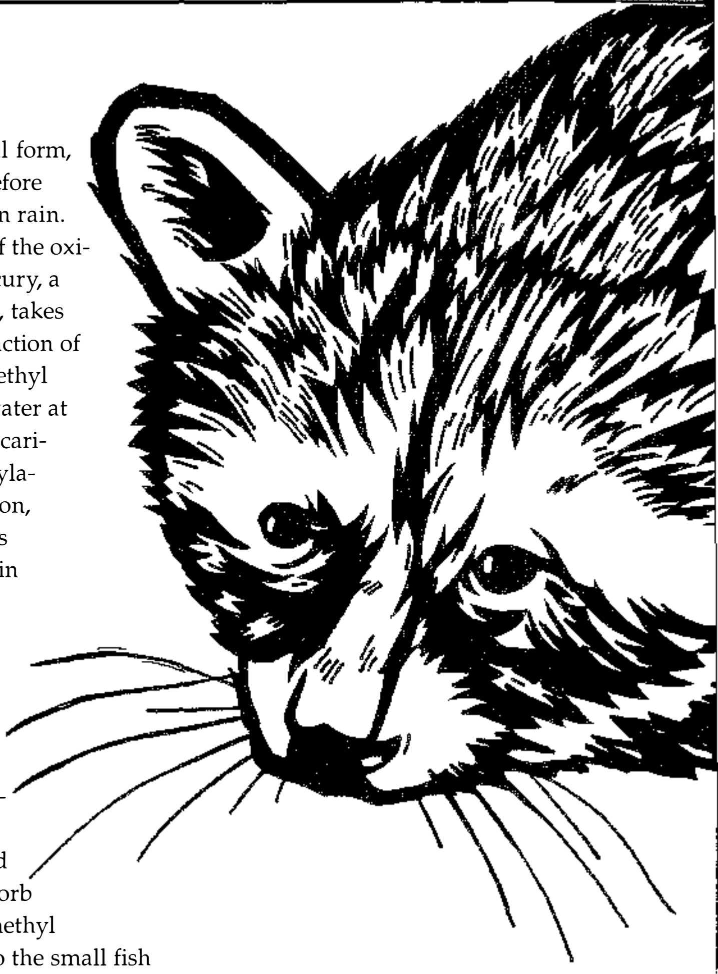


the Everglades some bass species have been found with mercury levels up to 4.4 ppm.

As a volatile, chemically active element, mercury undergoes a complex cycle in the environment. The average residence time for mercury in the atmosphere is approximately one year, but little is known about how far it is transported during that time or what chemical reactions it undergoes before returning to the earth's surface. Approximately one-third of the mercury in the atmosphere is thought to come from human sources, with about half of this fraction resulting from worldwide fossil fuel (mainly coal) combustion. Since power plants in the United States account for about 17% of global coal combustion, the contribution of U.S. utilities to total atmospheric mercury loading amounts to something under 3%. Recent amendments to the Clean Air Act charge the U.S. Environmental Protection Agency (EPA) with conducting a four-year study of mercury emissions and recommending possible control measures.

Once deposited in a lake, mercury undergoes a complex series of physical and chemical changes. Some of it remains in solution, some volatilizes back to the atmosphere, and some precipitates into sediments. While acidification has been suspected of accelerating uptake into the food chain, the exact nature of this role has not been clear. In particular, the effect could result either from pH changes per se or from the addition of sulfate ions in acid deposition. The presence of dissolved organic carbon may either foster or inhibit uptake, depending on conditions, but again the reasons have remained obscure.

One of the most important issues is what environmental factors influence the formation of methyl mercury—the element's most toxic chemical species and the one most easily incorporated into an aquatic food chain. More than 95% of the mercury in fish is in the form of methyl mercury. Most atmospheric mercury occurs simply in its elemental form, which must be oxidized before being carried to the earth in rain. In a lake, transformation of the oxidized form to methyl mercury, a process called methylation, takes place mainly through the action of bacteria. The amount of methyl mercury available in the water at any time depends on a precarious balance between methylation and its opposite reaction, demethylation. Researchers are particularly interested in determining what factors can tip this balance one way or the other.



Fish can absorb the methyl mercury directly through their gills or ingest it by eating smaller organisms. Both microscopic plants (phytoplankton) and animals (zooplankton) absorb considerable amounts of methyl mercury from the water, so the small fish that eat them receive an already concentrated dose. Large predatory fish then eat the smaller ones, and methyl mercury builds up in their bodies because it is difficult to excrete. Eventually, the magnitude of such bioconcentration becomes staggering—fish at the top of a food chain may have levels of methyl mercury a million times the level in the surrounding water.

The MTL project aims to examine all these aspects of the aquatic mercury cycle and has provided a model that can predict how much of the element eventually winds up as contamination in fish.

Clean hands, curtained lake

In their attempts to achieve these ambitious goals, MTL researchers have faced two particularly difficult technical challenges. The first is a need for extraordinary precautions to ensure that lake samples are not contaminated with even tiny amounts of mercury.

"Fish have been better mercury collectors than humans," observes project manager Donald Porcella of EPRI's Environment Division. "Over just a few years, as sampling techniques have improved, the estimates of mercury concentration in one lake have dropped by a factor of 500. We're talking about measuring one or two *billionths* of a gram of mercury in a liter of water. Understanding how fish living in such water can become contaminated enough to pose a risk to human health requires exquisitely careful collection and analysis."

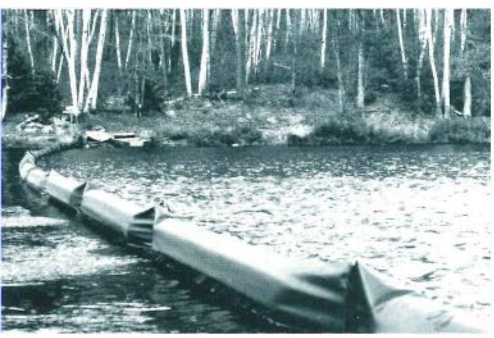
Among other precautions, researchers were swathed in nylon and plastic before leaning over the bow of a fiberglass boat to collect water samples while being driven slowly into the wind. Sampling bottles were coated with Teflon and then rinsed with acid. Even then, enough mercury leached from one bottle to double the estimated concentration. In the laboratory, contact with indoor air had to be avoided, and areas where contami-

Little Rock Lake

MAKING TWO LAKES FROM ONE

Little Rock Lake, an hourglass-shaped lake in northern Wisconsin, was the site of a study investigating the effects of lake acidification on mercury methylation and food chain contamination. The lake was partitioned with a flexible sea curtain at its narrow waist to create two approximately equal basins, one of which was treated with sulfuric acid and the other left in its natural state as a control. By using a single body of water for the experiments rather than separate lakes, researchers were able to focus on the effects of acidification while minimizing any confounding effects from other environmental factors.

Sea curtain



nated fish were studied had to be separated from areas where lake water was being examined. Finally, water samples were analyzed by three laboratories in different parts of the country. Because of this care, results from replicate samples and from analyses at the three laboratories were within a few percentage points of each other.

The other technical challenge faced in this study is the difficulty of isolating the effect of acidification on the mercury cycle from the effects of numerous other environmental factors—especially if experiments are conducted in two separate lakes. Therefore, the researchers decided to conduct their acidification experiments in a single lake that they could partition with a flexible sea curtain, with funding provided by the EPA. Little Rock Lake, in a remote area of northern Wisconsin, was chosen, in part because it is shaped roughly like an hourglass and could be divided into two approximately equal basins at its narrow waist. Sulfuric acid was then added to the 24-acre "treatment" basin, while the 20-acre "reference" basin was left in its natural condition. Little Rock is a seepage lake, so questions about in-lake processes could be addressed with less concern about methylation in the watershed or about the presence of large quantities of dissolved organic carbon, which is generally carried into drainage lakes by the streams that feed them.

A critical question about the role of acidification of lakes is whether it affects the rate of methylation by bacteria or the rate of methyl mercury uptake by organisms. Methylation is believed to take place in three relatively independent sites: lake water proper, the water-sediment interface, and buried sediments.

THE STATE OF THE ART IN SAMPLING

In the past, the contamination of water samples during collection and analysis was a major barrier to developing accurate estimates of mercury concentrations in lakes. For the EPRI work, strict protocols were used both on the lake and in the lab. The provisions included use of pretreated Teflon-coated collection bottles, independent analysis of samples at multiple facilities, high-efficiency filtration of laboratory air, and regular cleaning of all equipment with specially distilled acids. These procedures have allowed researchers to accurately measure as little as a few hundredths of one billionth of a gram of mercury in a liter of water.

Cleaning Up Mercury: First Field Trial of Genetic Ecology

Reality Lake test enclosures

While attention is for the most part focused on identifying the causes and extent of mercury contamination in remote lakes, revolutionary new cleanup techniques are about to be tested in a heavily polluted stream and pond in Tennessee. These techniques derive from the new science of genetic ecology—the study of how environmental factors influence microbial activity at the genetic level. By changing some of these factors in the contaminated waterways, scientists hope to stimulate bacteria to decrease the amount of methyl mercury available to the aquatic food chain.

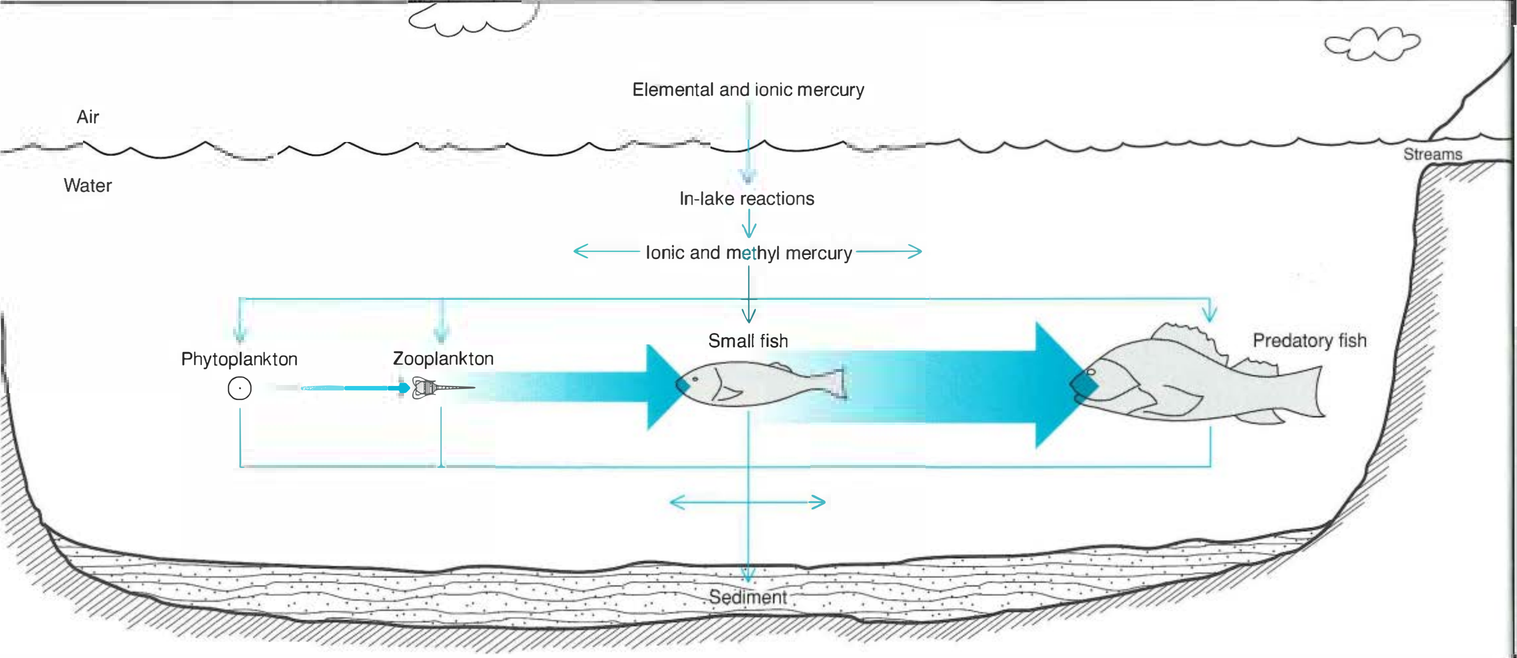
Natural detoxification processes, such as demethylation of mercury by bacteria, usually involve many separate biochemical reactions inside the cell. These reactions are catalyzed by enzymes, whose production is controlled by sequences of genes—called operons—that are turned on and off as a unit. Operons may also be duplicated and transferred from one bacterium to another. Genetic ecology identifies which of the operons required for a particular detoxification process are present in the bacteria at a contaminated site and determines how the operons' activity can be enhanced.

Although the principles of genetic ecology have been tested in the laboratory for some years, no attempt has yet been made to apply them on a large scale to aid in bioremediation—the use of natural processes to clean up the environment. Earlier attempts to stimulate bacterial activity at polluted sites involved only very general measures, such as adding nutrients. Now, for the first time, detailed knowledge of the processes by which specific bacterial operons control mercury detoxification will be used to enhance these processes for the bioremediation of a severely contaminated waterway.

East Fork Poplar Creek, which originates at a U.S. Department of Energy nuclear facility in Oak Ridge, Tennessee, receives roughly 30 grams of mercury per day from the facility's extensive subsurface drainage system. In an attempt to reduce mercury output downstream, a 2.5-acre plastic-lined pond, called Reality Lake, was constructed along the creek in 1988. During the past four years, researchers at DOE and the U.S. Environmental Protection Agency have been studying mercury transformations in the creek and lake and have concluded that the site might be amenable to bioremediation. EPRI has joined DOE and EPA in this jointly sponsored cleanup test.

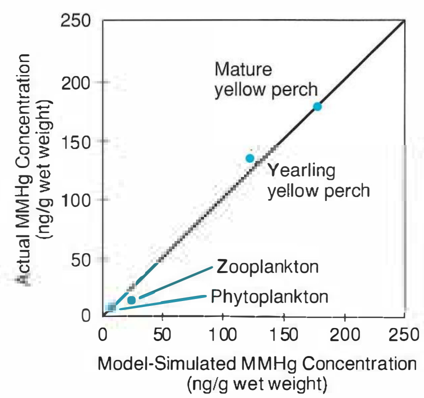
Using techniques developed from genetic ecology, bioremediation experiments will begin with work in closed, 4–6-liter laboratory containers called microcosms. These microcosms will contain water and sediments from the contaminated creek and will be used to simulate natural conditions. On the basis of studies conducted so far, scientists believe that increasing the carbon and phosphorus content of the water will encourage the reduction and demethylation of mercury by bacteria. Once a successful "recipe" has been found for stimulating these processes through changes at the genetic level, the experiments will be repeated in enclosures being constructed along the inlet channel from Poplar Creek to Reality Lake. All bacteria used in the outdoor experiments will be naturally occurring—either at the Oak Ridge site or elsewhere. Additional, limited experiments with genetically engineered bacteria will be conducted in the microcosms.

"We're on the threshold of a revolution in our ability to manage bioremediation," says project manager Robert Goldstein. "Our knowledge about microbial genetics is growing exponentially. This knowledge provides us with an extremely powerful tool that we can potentially use to reduce and clean up environmental wastes more effectively than we could with any other means available today—at a fraction of the cost. The work at Oak Ridge is important not only because it signals the first time genetic ecology has been used in field trials; it's also the first time that EPRI and EPA have signed a cooperative research and development agreement. This kind of agreement was made possible by the Federal Technology Transfer Act of 1986 and provides a good example of how public and private agencies can collaborate to develop a technology that is clearly in the public interest." □



MODELING MERCURY IN THE FOOD CHAIN **EPRI's Mercury Cycling Model, presented here in a much simplified form, can predict bioaccumulation of mercury at various levels of the aquatic food chain. Much of the fish contamination is due to the ingestion of microscopic phytoplankton and zooplankton, which absorb considerable amounts of methyl mercury—the most toxic chemical form—from the water. As large predatory fish eat the smaller fish, the bioconcentration becomes huge: fish at the top of the food chain can show methyl mercury levels a million times the level in the surrounding water.**

MODEL RESULTS ARE ACCURATE **Bioaccumulation simulations developed by EPRI's Mercury Cycling Model correspond very well to mean monomethyl mercury (MMHg) concentrations actually measured in Little Rock Lake biota. Perfect prediction by the model would put the data points exactly on the diagonal line.**



Thus, in addition to the water measurements taken from a boat, scuba divers collected sediment samples along a shore-to-shore transect in each of the Little Rock Lake basins. Also, one-year-old yellow perch were caught to use in determining the effect of acidification on mercury bioconcentration. Yellow perch represent about 90% of the total mass of fish in the lake, and the species is one of the most acid-tolerant in the region. Small perch are the preferred prey of larger predatory fish, such as walleyes, and thus play a key role in transferring mercury to these popular game fish.

In addition to the acidification experiments conducted at Little Rock Lake, comparison measurements were taken in other seepage lakes nearby. More than 30 researchers were involved in this phase of the MTL project, including scientists from the Wisconsin Department of Natural Resources, the University of Connecticut, the University of Wisconsin, Brooks Rand, Tetra Tech, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey.

First accurate inventory

The care taken by the MTL researchers has begun to pay off by making it possible to construct, for the first time, an accurate inventory of mercury in an aquatic system. By producing mass balances that show the amount of total mercury and methyl mercury held in various parts of the lake ecosystem, this research has also provided some initial answers to the key questions about how mercury cycles through the environment.

Specifically, the mass of mercury deposited from the atmosphere into seepage lakes appears to be large enough to account for the mercury contamination that has been raising concern. The treatment (acidified) basin of Little Rock Lake, for example, received about 1.05 grams of mercury per year from the atmosphere. The total mercury content of the basin itself (excluding sediments) was only 0.55 gram, of which 0.15 gram was found in fish and 0.3 gram was found in the water column. The remaining mercury found its way into sediments, which contained 0.1 microgram per gram of dry sediment.

Fish in the treatment basin, which had a pH 1.5 units lower than that of the reference basin, had 16% greater concentrations of methyl mercury than those in the reference basin. This finding indicates that the addition of sulfuric acid to the lake itself, rather than changes in the watershed, could account for the greater uptake of mercury into the food chain. In addition, experiments by other researchers using a radioactive mercury isotope as a tracer suggest that acidification increases the production of methyl mercury both in the water column and at the water-sediment interface. Taken together, these results indicate that acidification could foster contamination of the food chain by increasing methylation. A comparison of data from several seepage lakes in the same geographic region showed higher concentrations of total mercury and methyl mercury in the water from lakes that had lower pH levels. Considerable caution is required, however, in interpreting these results: none of the Wisconsin lakes appears to be substantially affected by acid deposition, so it is difficult to make inferences about the much more highly acidic lakes of the Adirondacks—where mercury contamination of fish has not been identified as a problem.

"The results of the Wisconsin lakes study provide us with the first accurate picture of the aquatic mercury cycle," says Don Porcella. "This picture was made possible only through the extreme care taken by the researchers involved. Not only are their data among the most accurate ever produced in this field, but their measurements of mercury concentrations in water were below even the detection limits of most prior work. They have clearly set a standard for the future."

Toward a model

Because of the accurate data available from the field study part of the MTL project, researchers have been able to develop a mathematical model to predict how mercury contamination in lakes and fish could change in response to shifts in various environmental factors—including mitigation efforts. This tool, called the Mercury Cycling Model, is currently being tested and should be ready for release by January 1992.

In the model, data on mercury concentrations in precipitation, lake water, and groundwater are used to predict the bioaccumulation of mercury at various levels of the aquatic food chain. So far, the model has produced more-accurate predictions than ever possible before, largely because it incorporates many aspects of the complex mercury cycle that were previously not well understood. Some uncertainties remain, which will require further experimental investigation to resolve. What, for example, is the impact on lakes of the chemical form of mercury emissions to the atmosphere? Also, what specific types of microbes control methylation and demethylation, and how could their activity be altered?

In addition to the effort just described, research is beginning to pin down other uncertainties about mercury in the environment. A comparison of the atmospheric deposition data from Wisconsin with similar data from the Olympic Peninsula in Washington State reveals very little difference in the amount and form of mercury being deposited in remote lakes. This finding suggests that mercury in the atmosphere tends to have a global cycle, although major sources of emissions would presumably create higher local levels of deposition. The PISCES project, mentioned earlier, is currently examining power plant emissions of mercury and also the effectiveness of various control devices to curb mercury emissions. Published data on the effectiveness of scrubbers, for example, report mercury reductions over a very wide range—from 25% to 95%—largely because of design differences and possible sampling and analysis difficulties.

Research on drainage lakes with large amounts of dissolved organic carbon indicates that, unlike seepage lakes, they may receive much of their methyl mercury from methylation in the watershed. The probable reason is that such lakes—which may contain so much dissolved material that they are cloudy and colored in appearance—receive most of their burden of organic carbon from streams. Research on geologic processes that might affect the mercury content of drainage lakes is still under way.

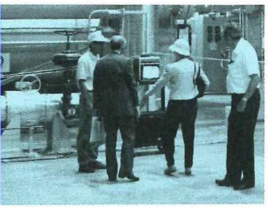
Finally, researchers are exploring ways to effectively detoxify mercury in lakes through bacterial demethylation. The emerging science of genetic ecology attempts to enhance such natural detoxification by stimulating the duplication and transfer of sequences of genes, or operons, among bacteria through environmental modification (see the sidebar).

"Mercury provides a good blueprint for studying other trace elements in the environment," says John Huckabee, manager of EPRI's Ecological Studies Program. "Development of analytical methods for determining the behavior of various chemical forms of trace elements is important to assessing their ecological effects. We can't really make informed decisions about trace elements in the environment until we know how they are transformed and are transported in food chains." ■

CONFERENCE ANNOUNCEMENT

An international conference on mercury as a global pollutant will be held May 31 to June 4, 1992, in Monterey, California. This conference will provide a forum for the presentation of research results on the ecological and health aspects of mercury in the environment. Its objectives will be to integrate and synthesize current knowledge and to identify information needs for the development of an assessment framework. For program, registration, and accommodation information, contact Pam Turner at EPRI, (415) 855-2010.

This article was written by John Douglas, science writer. Background information was provided by Don Porcella, Robert Goldstein, and John Huckabee, Environment Division.



Alabama Cooperative Generates

As the part-time mayor of McIntosh, Alabama (population 400), Carrol Daugherty has witnessed a profusion of curious visitors pass through his "little old lazy town" over the past few years. These people have made their way from all corners of the United States and even from overseas. They didn't come for the fishing and hunting, which Daugherty says is the best in the state. They came to learn about the nation's first compressed-air energy storage (CAES) plant.

What's unique about the 110-MW facility owned by Alabama Electric Cooperative (AEC) is not so much what visitors *can* see as what they cannot—particularly the plant's 19-million-cubic-foot underground cavern, which is tall enough and wide enough to contain a 100-story skyscraper. During AEC's off-peak hours, when demand for electricity is at its lowest levels, electricity from a nearby coal-fired plant is used to compress air and store it in the cavern. During periods of higher demand, the air is released, heated with oil or natural gas, and expanded through the plant's turbine to generate electricity. The plant can produce enough power to serve 36,000 homes during peak demand periods.

The plant took two years and nine months to build. First brought on-line on May 31 of this year, it has been through a series of test runs and was officially dedicated on September 27, AEC's 50th anniversary. About 1200 people attended the event, including utility representatives from across the United States and from Germany and Japan. Among those present were EPRI's president and CEO, Richard Balzhiser; Bob Bergland, executive vice president of the National Rural Electric Cooperative Association; and the governor of Alabama, Guy L. Hunt.

"We hope this project helps dispel some of the myths about rural electric cooperatives," says Phillip Burgess, communications manager for AEC. "Some

THE STORY IN BRIEF

Alabama Electric Cooperative marked a milestone in the history of the electric utility industry with the dedication of the nation's first compressed-air energy storage plant on September 27. Located in McIntosh, Alabama, the 110-MW facility compresses air into a 19-million-cubic-foot underground cavern during periods of low electricity demand. During periods of peak demand, the air can be released, heated, and expanded through a turbine to generate electricity as needed. Overall during the generation period, the plant uses one-third of the fuel required by a conventional combustion turbine power plant and, as a result, releases one-third the emissions. EPRI studies show that 75% of the country's geology has the potential to provide reliable underground air storage. A dozen other utilities are seriously investigating the implementation of this technology.

Power From Air

DEDICATION DAY

Some 1200 people, including delegates from foreign countries, attended the dedication of the first U.S. compressed-air energy storage plant, in McIntosh, Alabama, on September 27.

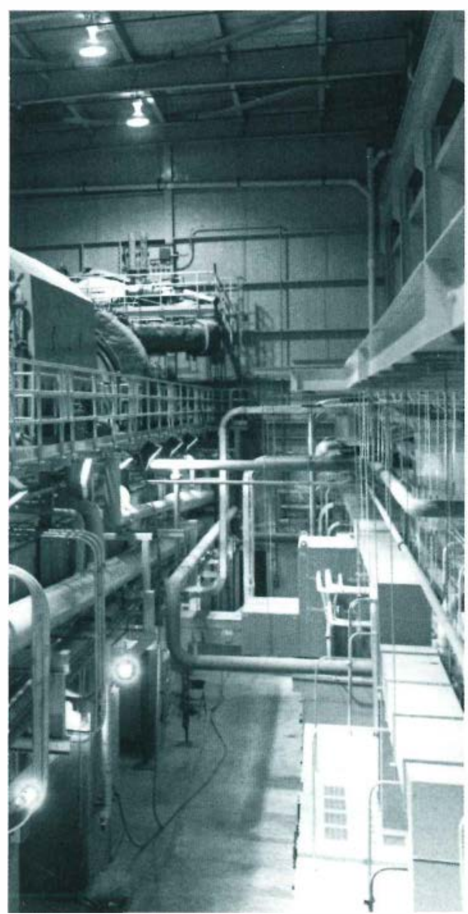
people in the industry perceive the cooperatives as backward, having outlived their usefulness. Yet it's a rural electric cooperative that has brought on-line the first use of CAES in the country. We're on the cutting edge of technology."

Aside from the novelty of CAES technology, what makes AEC's plant so significant is that it was built specifically for commercial use, to help meet the electricity needs of AEC's customers. As Robert Meyer, the CAES project manager at AEC, puts it, "This is no research project. This is for real."

There is one other commercial CAES plant in the world, a 290-MW (50-Hz) facility in Huntorf, Germany. This plant has been operating successfully since 1978, demonstrating 90% availability and 99% starting reliability.

The McIntosh plant is intended to improve upon the CAES technology demonstrated in Germany. It contains one significant feature, a recuperator, not found in the Huntorf plant. Provided through EPRI's technical and financial assistance, the recuperator uses waste heat to preheat air from the cavern before it is heated in the combustor. This reduces consumption of premium fuel by about 25%. Overall during the generation period, the plant uses one-third the fuel required by a conventional combustion turbine power plant and as a result releases one-third the emissions. EPRI contributed $8 million to the $65 million project.

In his speech at the dedication ceremony, Balzhiser said AEC's plant "symbolizes a new wave of technological advancement that will transform the electric power industry in coming decades." In-



From left to right: Malloy Chandler, AEC Board of Trustees; Robert Thompson, Pea River Electric Cooperative; James A. Vann, Jr., AEC; Guy L. Hunt, governor of Alabama; Bob Bergland, NRECA (at podium); Richard Balzhiser, EPRI; J. E. (Gene) Smith, National Rural Utilities Cooperative Finance Corporation.

deed, storage technologies like CAES offer an economical means for utilities to increase their control over the delicate balance between demand and supply in an electricity market that is growing increasingly uncertain. A number of other utilities investigating the implementation of CAES technology are watching progress at McIntosh closely.

Never intended to be first

While AEC representatives are certainly proud of being the first utility in the country to implement CAES, they don't hesitate to admit that they never planned for things to happen that way. "We really didn't choose to be first," explains John Howard, vice president of power production for the utility. "We just happened to need additional capacity, and CAES provided that capacity at an attractive price." Howard says the cost of CAES compared favorably with the two other options the utility was considering at the time—simple-cycle combustion turbines and combined-cycle fossil plants.

Howard says AEC's demand has been growing steadily at about 4% a year for the past several years, a rate that he expects will continue over the next decade. "We're depending on this plant to help us meet our generating responsibilities," he said during an interview in August, noting that the plant already had generated 16 million kWh that were delivered to AEC customers. "If that electricity had not come on-line, we would have had to purchase the power," he said.

Among other benefits of the CAES plant, startup time is quick—about 9 minutes for an emergency start and 12 minutes under normal starting conditions. By comparison, combustion turbine peaking plants typically require 20–30 minutes for normal startup. Another advantage is that the plant can respond swiftly to fluctuations in load, following load shape to supplement supply as needed, with minimal change in generating efficiency. The plant can be remotely controlled, requiring a minimal on-site staff.

The McIntosh plant represents about 14% of AEC's generating capacity. The utility plans to run the unit about 1700 hours a year. Howard anticipates that it will be used an average of five days a week from June through early September and two or three days a week during the winter months. In the fall and spring, the plant may be used to supply some capacity while the utility's large coal-fired units are down for maintenance, he says.

To the layperson, the McIntosh plant, located off U.S. Highway 43 about 45 miles north of Mobile, could pass for a typical generating station. Indeed, basic components of the station, including its compressor, combustor, and expansion turbine, are similar to those found in conventional, gas-fired combustion turbine plants. But the air storage cavern, which lies 1500 feet below the ground and measures 1000 feet in height and 240 feet in diameter, is clearly unique for the U.S. electric utility industry.

The man-made cavern is located in the tip of a vast underground salt dome that is about 1.5 miles in diameter and at least 8 miles deep. It was created through a solution-mining process, in which fresh water was injected into the dome to dissolve the crystalline salt. The walls of the cavern can withstand pressures of about 2000 pounds per square inch, roughly twice the maximum air pressure in the cavern when the plant is in use.

While salt domes are a new storage mechanism for the U.S. electric utility industry, they have served other storage purposes for years. For example, all of the country's strategic petroleum reserve is housed in salt domes. Also, the gas and petroleum industries worldwide have successfully stored hydrocarbon fuels in more than 200 salt caverns for over 70 years. Germany's Huntorf CAES plant uses salt caverns for storage. But salt caverns are not the only effective underground storage vessels; porous-rock formations and hard-rock caverns also can be used to store compressed air.

The world's only other CAES facility—a 25-MW demonstration unit in Sesta, Italy—successfully used porous rock to store compressed air. This facility is no longer in operation. To date, no CAES plant has used a hard-rock cavern for storage, but a utility in Japan is currently building such a plant. The 35-MW, six-hour commercial unit is scheduled to go on-line in April 1997. In other worldwide activity in CAES, a utility in Israel plans to build at least 300 MW of CAES capacity using salt domes and possibly porous-rock media for storage. Also, plans were under way in Russia to build 1050 MW of CAES capacity using salt caverns. It is not known whether the recent political changes in the Soviet Union have altered these plans.

Extensive research conducted by EPRI in the late 1970s shows that 75% of the country's geology has the potential to provide reliable underground air storage. But despite the success of CAES as demonstrated in Germany, U.S. utilities have not jumped on the opportunity. "No one wanted to be first in this country," says Robert Schainker, manager of the Energy Storage Program at EPRI. "The people at AEC took on the challenge of being first, trusting that if they worked with EPRI, this concept on paper could actually be built and work. To be first on such a project is a major achievement for any utility today."

Benefits of storage

Aside from generating needed electricity, CAES provides a means for utilities to better manage the balance between supply and demand. As Schainker describes it, "We are running an intricate mix of generation in this country—a massive maze of wire and rotating equipment. Yet it is so intrinsically unstable because utilities have got to generate electricity the instant somebody wants it. You need a shock absorber somewhere."

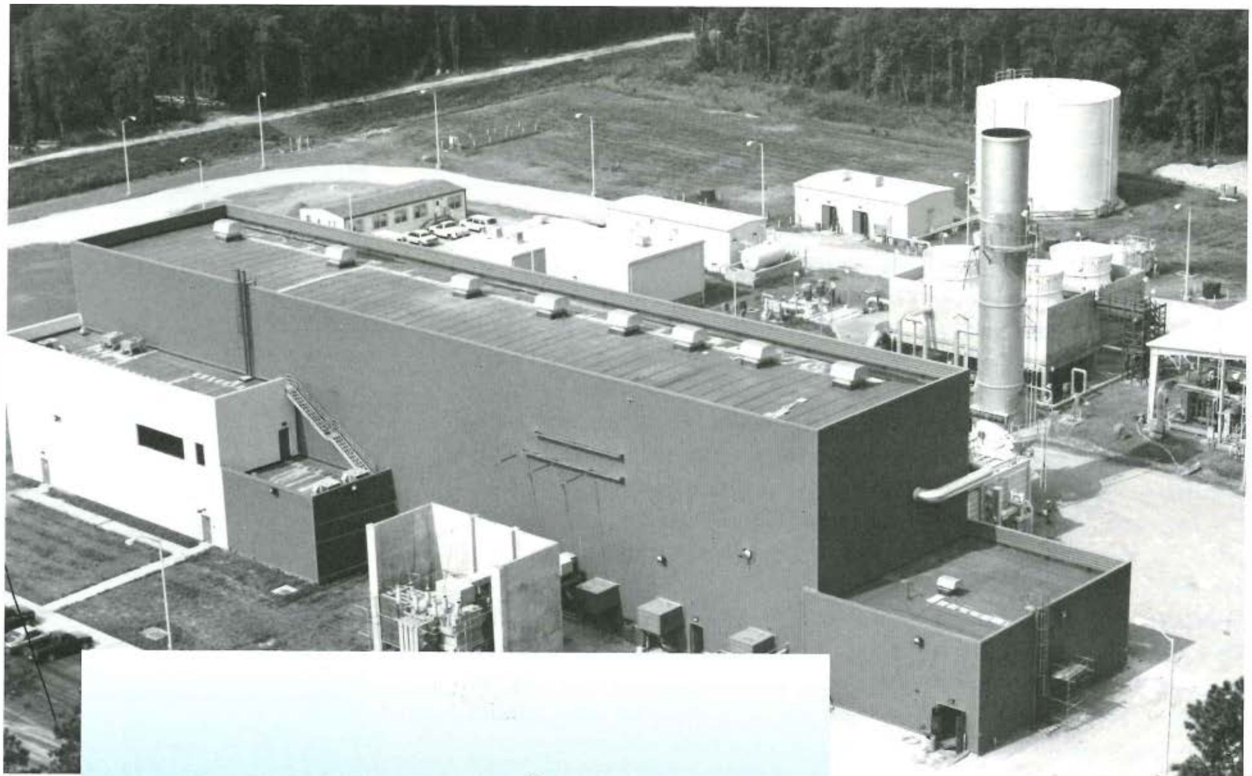
CAES and other storage technologies can function as shock absorbers, allowing utilities to store electricity, or electricity potential, for future use. But storage technology today accounts for only about 3% of U.S. generating capacity. This consists of 36 pumped-hydro plants, which pump water uphill during off-peak hours and release it to drive hydro turbines when demand increases. Other storage options under development include large-scale battery storage and superconducting magnetic energy storage.

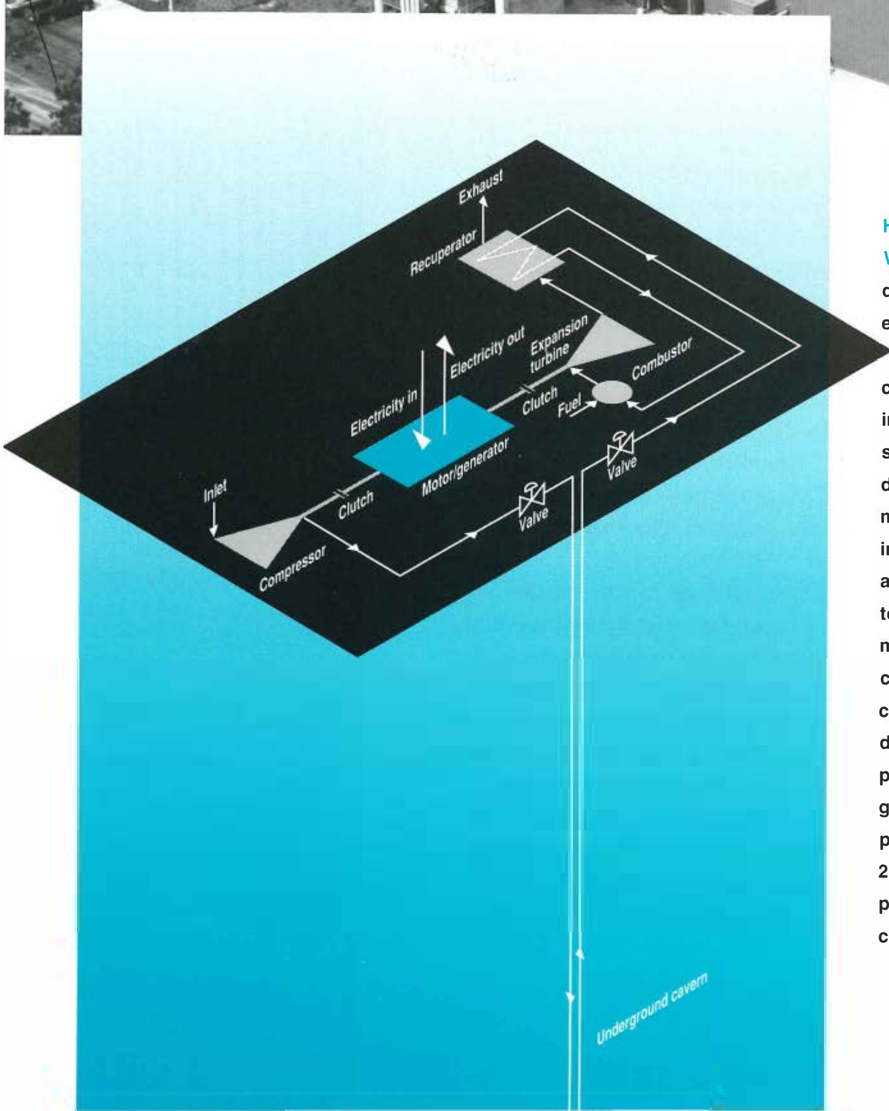
"AEC's success with the CAES project is a milestone on the way to EPRI's goal of broad implementation of storage technology, which is so important to our nation's energy future," says George Preston, EPRI's vice president for generation and storage. He notes that because utilities must build plants to accommodate peak demand, a good portion of installed capacity typically goes unused in the off-peak hours. "On average, utilities can use only 60% of their plant capacity. That compares with about 90% for other major industries," Preston says. "The storage option offers utilities a perfect opportunity to tap the full potential of their capital assets and maintain a competitive position as electricity suppliers."

"Today most utilities that are talking about storage simply evaluate it as another generation option, when in fact it's so much more than that," says James Birk, director of the Storage and Renewables Department at EPRI. "It's a way to improve the management of a system that is becoming much more difficult to control." As a strategic management tool, storage is similar to the hub-and-spokes service system used by the airlines, Birk says. "The idea is that the hub cities store passengers to improve the productivity of the system, allowing more customers to be transported with fewer planes. The hub cities are there not to supply passengers but to manage the supply."

As a means of meeting peak demand, storage technologies are much more flexible and often more cost-effective than the alternative of using oil- or gas-fired peaking plants. Strategic use of storage can also give utilities a competitive edge, says Birk. Among other benefits, it can give utilities leverage in purchasing electricity, minimize the risk of unexpected changes in fuel costs and load shape, and help ensure that customers receive reliable electricity service. Storage can also be used as a tool to manage emissions from generating plants to ensure that utilities meet increasingly stringent emissions limits in the most cost-effective and timely way.

"What we're finding is that energy stor-





HOW THE CAES PLANT WORKS During periods of low demand, relatively inexpensive electricity from a nearby plant is used to power a motor that compresses air. The air is piped into an underground cavern for storage. When power is needed during periods of higher demand, the air is released, heated in combustors with gas or oil, and expanded through turbines to drive the generator. The motor and the generator are combined in one machine; clutches decouple the turbines during compression and decouple the compressors during generation. A recuperator cuts premium fuel consumption 25% by using waste heat to preheat the air flowing to the combustors.

age is absolutely essential to a utility's becoming very competitive and strategically positioned to reduce emissions and capital requirements in the future," says Dale Bradshaw, a program manager at the Tennessee Valley Authority, the chairman of EPRI's Energy Storage Program Committee, and a member of the CAES working group established by EPRI. The working group, which consists of representatives from about 45 utilities, has been overseeing progress on AEC's plant. Bradshaw notes that storage technologies like CAES can be particularly valuable when used in conjunction with renewable energy resources like solar energy and wind power, which are not always available when needed.

TVA, Pacific Gas and Electric, Public Service Electric & Gas, and Carolina Power & Light are among a dozen utilities that are seriously investigating the implementation of CAES. But will others in the industry follow suit? "Right now there is a tremendous amount of enthusiasm in the industry for combustion turbines," Birk says. "If you look at the trends and the business reports, you get the impression that no utilities are thinking about compressed-air energy storage."

However, Birk believes that interest will increase as utilities become familiar with the advantages storage offers. Already, CAES has gained the support of many outside the industry, including environmentalists. According to a recent article in the *Los Angeles Times*, "Environmentalists are enthusiastic about the [McIntosh] plant, because it uses ordinary air, not an exotic or potentially hazardous substance, for storing energy." In the article, Warren Liebold, a member of the Sierra Club's national energy committee, calls CAES technology "relatively benign, environmentally."

"I think that we are breaking the ice with AEC and some of these other utilities now actively pursuing CAES," says Birk. "Once the ice breaks, we are going to see some significant movement toward the widespread implementation of CAES."

CAES pioneers

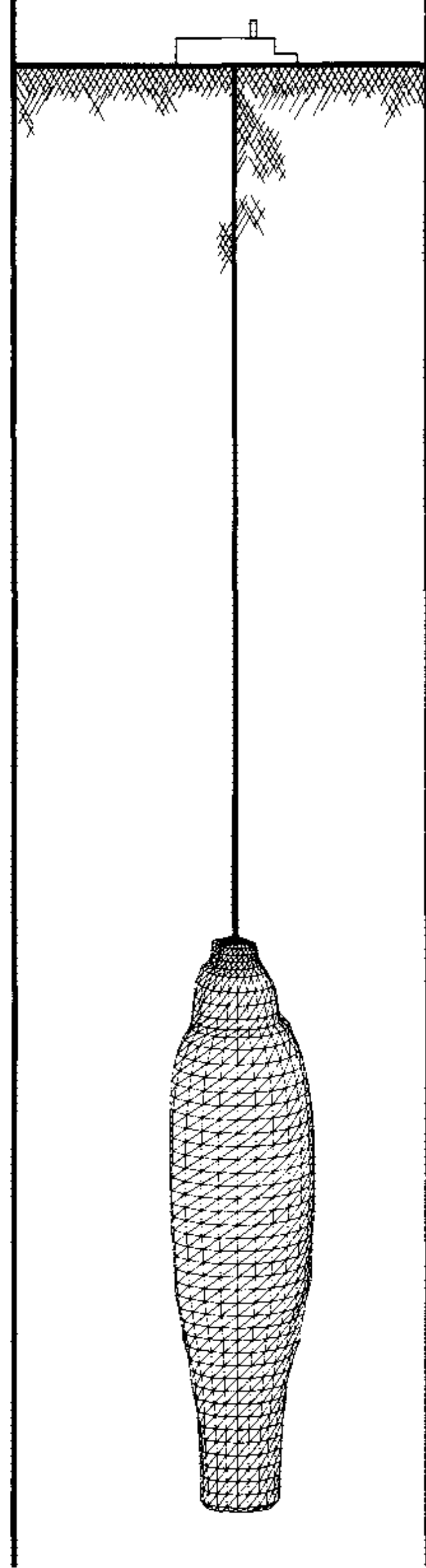
When AEC first began investigating the potential for CAES in 1977, the only system on the market was a 220-MW unit from Brown Boveri (now Asea Brown Boveri), which was too large and costly for AEC's needs. EPRI was discovering that other utilities had similar reactions. The Institute had undertaken extensive studies on the technical and economic feasibility of employing CAES in the United States and had identified about 20 utilities that were strong CAES candidates. Not one of them was interested in a 220-MW unit.

After further studies, Schainker discovered that all the components required for smaller units were available off the shelf and were being used for various purposes in other industries. Schainker proposed that the smaller components be combined to create "mini-CAES" units, ranging from 25 to 100 MW. An added benefit of the smaller units was that, because more manufacturers were already involved in producing the components, prices were competitive.

The mini-CAES concept made the technology economically feasible for AEC. But as Schainker points out, there were other hurdles to overcome. In particular, he says, "the people factor is critical. You need willingness from top management to venture into unfamiliar technical terrain. A lot of utilities we had been working with did not show this willingness." At AEC, however, CAES had the support of Ray Clausen, the head of planning, and of Charles Lowman, the former general manager of the cooperative.

Logistical problems involving the site for the project also had the potential to stand in the way. But in this area too, AEC was well positioned. Olin Corporation's Chemicals Division, which operates a large chloralkali plant in the region, agreed to lease AEC a 40-acre parcel directly above the salt dome AEC wanted to mine. The utility and the chemical company signed an agreement under which Olin would supply fresh water for the so-

FACTS AND FIGURES O



[H]E MCINTOSH PLANT

- Compressed air flows through the generator at a rate of 340 pounds per second, about the rate at which air flows through a 747 jet engine.
- The solution-mined salt cavern measures 1000 feet tall and 240 feet wide. Its ceiling is 1500 feet below the ground.
- The cavern is located in a massive salt dome that is about 1.5 miles in diameter and over 8 miles deep.
- Air pressure in the cavern ranges from 650 to 1055 pounds per square inch.
- The cavern walls can withstand pressures of 2000 pounds per square inch, about twice the cavern's top operational pressure.
- The plant can change load at a rate of 30% (33 MW) per minute, about three times faster (on a percentage basis) than any other type of power plant.
- The plant operates efficiently at part load, losing only 15% in efficiency when running at 20% capacity. By comparison, conventional coal-fired plants would lose about 50% in efficiency at such partial load.
- The bulk of the $65 million project was paid for by AEC. Cofunders include EPRI, which contributed $8 million, and the National Rural Electric Cooperative Association, which contributed $660,000.

lution-mining process and the resulting salty water, or brine, would be piped back to the company for use in its chemical processes.

By mid-1988, bids for the project were awarded. Dresser-Rand would supply the machinery, Gibbs & Hill would serve as the engineer, Fenix & Scisson would solution-mine the cavern, and Harbert International would construct the plant. AEC broke ground on the project in October 1988, and before long, engineers and executives from dozens of utilities across the country, and also from foreign countries like Japan and Israel, were paying visits to the cooperative.

Howard recalls that he and others involved in the project viewed the development of the salt cavern as the greatest risk. As it turned out, the mining process went very smoothly and was completed on schedule. But there have been other challenges along the way. As Birk describes it, the McIntosh plant has experienced some "teething" problems, which can be expected in the construction of any new plant. The most significant problem occurred early in August 1991, when the metal linings inside the plant's two high-pressure combustors cracked. Shortly after the incident, test liners were installed. Experts have been examining them periodically to determine how well they perform. Ultimately they will be replaced by permanent liners. AEC expects that all the bugs will be worked out of the new system by the end of the year.

Throughout the AEC project, EPRI has provided engineering support. The Institute has also been monitoring the performance of the plant, with careful attention to the recuperator and the cavern, among other components. The monitoring process will continue for at least one year. As information is gathered and analyzed, results are being made available to all EPRI members. AEC also will be paying close attention to this information, since the McIntosh site has been laid out to accommodate a second unit.

EPRI is developing a number of tools that will be of use to utilities interested in CAES. Among them are a "lessons learned" document based on the AEC project and a computer simulation of CAES that will give operators and others a sense of the technology's fast response time and other capabilities. In the meantime, the Institute is working on further improvements to CAES. One possibility under study is the incorporation of a humidifier that will combine waste heat and water to increase significantly the energy content of the mass flowing through the turbine, providing additional power without requiring an increase in the unit's size. EPRI is also investigating the use of high-temperature turbine technology, as well as technology that reduces nitrogen oxide emissions.

At this time it is not clear how soon other utilities will implement CAES. But TVA is among those that appear ready to forge ahead. According to Dale Bradshaw, TVA is considering adding 600–1200 MW of CAES capacity. Already the utility has committed about $1 million to geotechnical studies and has selected a primary site—a depleted natural gas field in porous rock. At this writing, TVA is in the process of drilling into the depleted field and plans to withdraw a core sample for further studies. A final decision on whether and where to implement CAES will depend on the outcome of these and other studies. If all goes smoothly, Bradshaw says, TVA's first CAES unit could be on-line early in 1996.

"We've been trying to build on the tremendous success of the AEC project," Bradshaw says. "They have been true pioneers. If they had not built their plant, I doubt we would be as far along as we are with CAES. I'm hoping that TVA can take it the next step and that AEC and other utilities can learn from us."

This article was written by Leslie Lamarre. Background information was provided by James Birk, Robert Schainker, Robert Pollak, Ben Mehta, and Jim Goodson, Generation and Storage Division.

LIGHTS! CAMERA! AND... MAINTENANCE!

THE STORY IN BRIEF

After proving invaluable in the Three Mile Island cleanup during the 1980s, video cameras are now finding widespread use in a variety of nuclear plant maintenance applications. Much more resistant to radiation damage than previously thought, low-cost off-the-shelf industrial units can save a utility dozens of person-rems of exposure a year by substituting for workers in low to moderate radiation fields. And while commercial maintenance companies will contract for such video services, an EPRI survey shows that many utilities are successfully putting their own systems together for such procedures as job planning, worker training, remote maintenance monitoring, and weld inspection. Beyond conventional setups, electronic still-video imaging systems linked to computers promise to revolutionize documentation capabilities, and digital video input to CAD/CAM systems may eventually allow three-dimensional modeling of plant areas.

Closed-circuit television has long been used in nuclear power plants for remote observation in fuel inspection and security-related functions. But it took off in a big way in the 1980s during cleanup of the accident at the Three Mile Island Unit 2 reactor. High radiation fields in many parts of the plant forced crews to develop numerous innovative applications of both robotics and video in order to minimize occupational exposures. Video cameras were in constant use at TMI-2 throughout most of the decade, monitoring worker safety, serving as the eyes of robotic decontamination vehicles, and guiding underwater work to remove the damaged reactor core, among many other tasks.

Since then, video equipment has become so inexpensive, simple, and easy to use that many businesses and consumers alike now routinely record everyday events, from employee training seminars to neighborhood softball games. And as nuclear utilities increasingly recognize the value of video in enhancing worker

productivity and reducing radiation exposure, light, inexpensive cameras and related gear are becoming standard equipment for everyday operations and maintenance (O&M) jobs.

Temporary as well as permanent camera placements allow maintenance supervisors or health physics (HP) technicians to remotely observe work in a radiation control area from a low-exposure location. Cameras are also being used to survey work areas before a maintenance job begins and thereby plan the activity to minimize work time and personnel exposure. In addition, many plants are using new, interactive videodisc plant walk-through systems that contain thousands of images of specific locations and equipment. And a few utilities are exploring electronic imaging systems that combine high-quality digital still-video images with desktop publishing capabilities for improved documentation of O&M activities.

In a recent survey of video use in nuclear plants, EPRI documented the benefits of 19 utility applications at boiling water reactors (BWRs) and 16 at pressurized water reactors (PWRs). A report on the survey results (NP-6882) also outlines the basic elements of closed-circuit video systems and describes approaches to using them in power plants.

As equipment continues to drop in cost and its use widens, a concern among engineers that has sometimes inhibited the use of video in nuclear plants is fading: that cameras won't perform well or for long in the presence of radiation fields. Utilities are finding that commercially available industrial video cameras are fine for most work in low to moderate radiation fields, despite a potential for some browning of the lens at higher gamma exposures. For such applications, the units can be placed in environmental housings for protection from heat, moisture, and radiation and thus can have substantial service life. In fact, experience has shown that they are more likely to fail from general wear than from radiation damage. The gear can also be partly or largely decontaminated for reuse.

With the cost of some cameras as low as $300, the value of the occupational radiation exposure they help avoid far outweighs the cost of disposal and replacement of cameras that get too contaminated or damaged by radiation. Results of the EPRI survey indicate exposure savings of as much as 75 person-rems over the course of a year at one plant and a reduction of a factor of 10 at another. As part of extensive programs to keep occupational exposures as low as reasonably achievable, utilities assign values of up to $10,000 per person-rem avoided.

"There is so much emphasis on avoiding personnel radiation exposure that even modest savings from the use of video are very well received by utilities," notes Dennis Owen, president of ENCORE Technical Resources, the Middletown, Pennsylvania, consulting firm that conducted the survey for EPRI. "Just avoiding 2 person-rems could represent a $20,000 savings to a utility. If the utility spent some engineering time and $1000 for equipment to achieve that savings, it would clearly be worthwhile." Nuclear plant workers are currently limited by regulation to a maximum of 5 rems of exposure in a year, but many utilities try to maintain management-established goals that are even lower. There is also the possibility that recently tightened international standards for radiological protection could lead to lower U.S. occupational exposure limits in the future.

Video tools for O&M

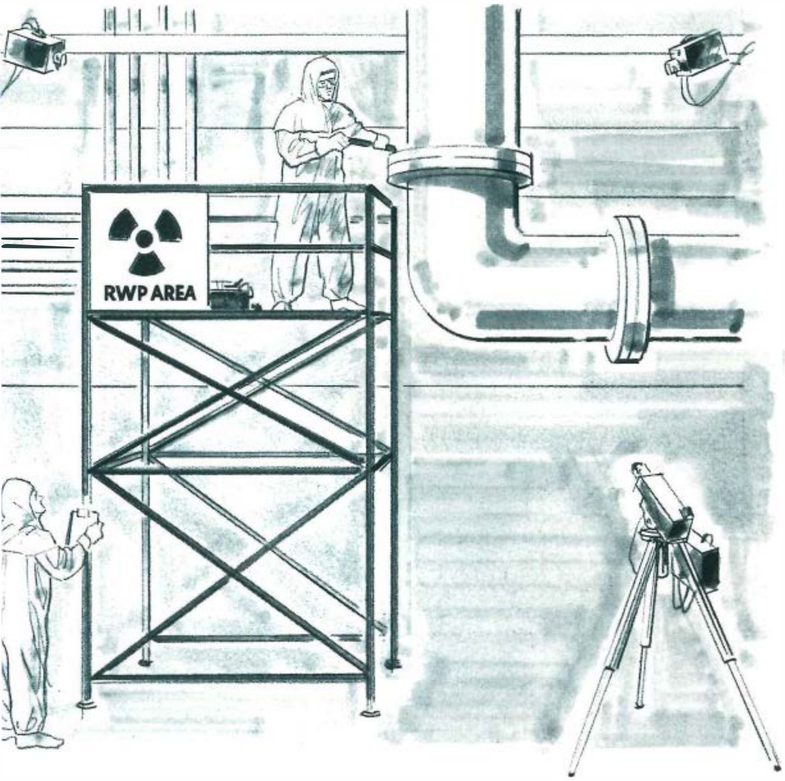
After documenting the extensive use of video in the cleanup at TMI–2 during the 1980s, EPRI has shifted its focus toward gathering and disseminating information on individual utility experience with video equipment as part of a broader program addressing industrial safety equipment and practices at nuclear power plants.

Says John O'Brien, a program manager in the Nuclear Power Division, "The main value of video is to provide a window on a job so that you can minimize the amount of time a worker has to spend in a radiation control area or can avoid having to send a supervisor or HP technician into the area at all. We have documented significant exposure savings, but there are other, less easily quantifiable savings as well. For example, sending fewer people into what is often a cramped work area definitely improves work flow, communication between workers and supervisors, and productivity. And being able to get a job done faster—during an outage, for example—because you have a camera instead of more people observing the work, or because you need fewer crews to finish it, can translate into reduced costs for replacement power. There is also the value of real-world video pictures of various work for training purposes. But these kinds of benefits are harder to document."

A video system for industrial application generally consists of a black-and-white or color camera; a general-purpose pan-and-tilt camera mount or a special mount; a remote unit for controlling the camera's zoom lens motion, lens aperture setting, and focus; and a video monitor (perhaps integrated with the control unit). Other components that are often needed include auxiliary lighting equipment, a videocassette recorder, and protective camera housings.

The two types of imaging system available in industrial video cameras pose a trade-off: cameras with conventional electron tubes are larger, more fragile, and more susceptible to image smear and burn, whereas cameras featuring charge-coupled device, or CCD, electronic imaging systems are more susceptible to ionizing radiation. Both types of system, however, are widely used in industrial and nuclear environments and are available in camera models specifically engineered for use in nuclear plants, the EPRI report points out.

Several commercial suppliers of general industrial and nuclear plant–related



ULTIPLE CAMERAS FOR MULTIPLE VIEWS **Nuclear plant video systems combine expensive cameras with a remote control and monitoring console to provide temporary permanent surveillance of work areas or activities. Such systems have substantially duced personnel radiation exposure during maintenance and inspection tasks at dozens plants. Shown here is a typical nuclear plant video application involving multiple ımeras in a radiation control area.**

specialty video systems, as well as a number of smaller firms, provide applications-oriented consulting and support services. The major nuclear plant maintenance service and reactor vendors use specialized underwater and radiation-hardened cameras as part of their services.

But many utilities are putting together their own systems and applying them with great success. ENCORE Technical Resources limited its survey of utility video use to applications developed by plant staff, excluding applications developed by the major reactor service companies and also security, robotics, communications, and public relations applications. Utility responses spanned a range of applications and varied widely in the level of detail about the benefits realized, but a sampling of highlights suggests that in all cases the benefit-to-cost ratio was strongly positive (see the sidebar).

Many nuclear plant uses of video, such as equipment inspections and remote observation of workers, are applicable to both BWRs and PWRs. Indeed, the EPRI survey found that video's use as a tool for remote monitoring of work accounts for the majority of applications, with HP support the largest reported use within the category. Another common application is the substitution of cameras for workers on fire watch during welding operations. In BWRs, two plant areas where video applications were widely reported by utilities are the refueling floor and the reactor vessel drywell. In PWRs, cameras are frequently used for surveillance inside the containment during power operation—for the monitoring of pumps and seals, for example.

"Video technology is increasingly finding its way into new niches throughout our plant," says Joe Sears, an associate senior health physicist at Niagara Mohawk Power Corporation, which has purchased about a dozen video systems for use at its two-unit Nine Mile Point plant in New York. Sears estimates that Niagara Mohawk avoided 15 person-rems of exposure in 1990 by using cameras, largely for routine inspections and HP support. And he adds that, beyond the exposure savings they afford, "video systems are really a major productivity tool for scoping out high-radiation areas and working conditions before going in to do a job. The productivity gains—from not having to suit up, log in, log out, go through decontamination procedures, and do the paperwork every time something needs to be checked—are substantial."

Niagara Mohawk, which is quantifying and documenting the benefits from its use of video in an EPRI Innovators applications analysis now in preparation, first heard about the systems through EPRI when the utility began exploring ways to reduce personnel radiation exposure. The utility quickly deployed video as the technology's exposure reduction potential became apparent. Sears stresses the importance of plant management's early interest in and commitment to the technology as a key to getting the widest use out of the equipment.

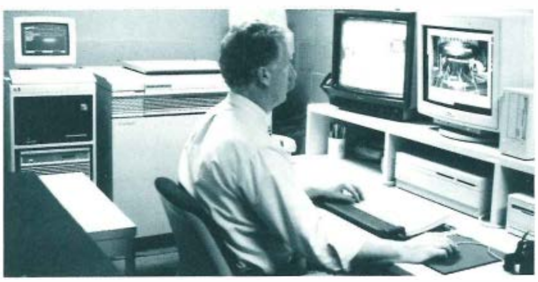
Digital video and beyond

In addition to conventional, real-time analog video, a number of advanced imaging technologies are already available or are expected to be available soon for use in nuclear plants. These include still-video and multimedia systems; surrogate plant walk-through systems; electronic still-video imaging with computer power for enhanced production capabilities; digital video input to computers used in design and modeling; and potential applications of photogrammetry (taking measurements from images). EPRI has just published a report on these new technologies (TR-100165), which is intended for use in conjunction with the video applications survey.

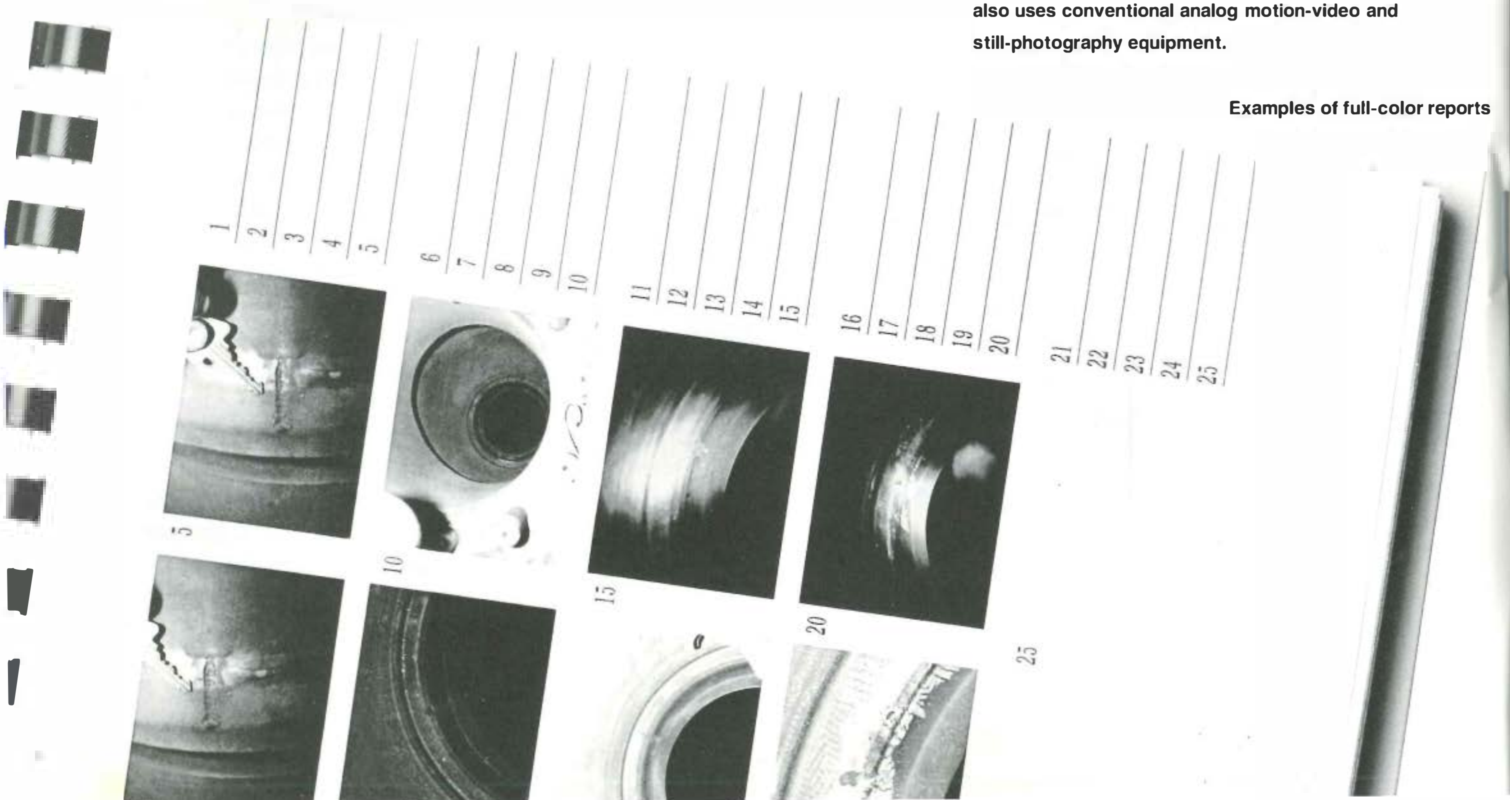
Many nuclear plants already have hired specialty contractors to make comprehensive photographic walk-throughs of their plants. These are produced with various media, often before plant startup or during an outage, since many areas are inaccessible during power operation. The thousands of location-referenced frames are stored on optical disc. The image

ADVANCED IMAGING SYSTEMS PIONEERED AT MILLSTONE At Unit 3 of the Millstone Point nuclear power plant in Connecticut, various personnel are pioneering the use of advanced still-video and digital image-processing systems in various engineering and operations tasks, including health physics support. Still-video images captured on magnetic microdiskettes can be viewed on a video monitor or, with the help of a computer workstation, can be electronically pasted into reports and documents that can be printed in full color. The station also uses conventional analog motion-video and still-photography equipment.

Electronic still-video workstation



Examples of full-color reports



records may then be accessed for a variety of purposes, including maintenance planning, training, or documentation.

In many cases, optical-disc-based images can be accessed interactively with proprietary computer software, a high-resolution monitor, and a joystick, with the user directing the surrogate walk-through down one walkway or the next, looking left or right, up, down, or back at will. Depending on the extent of the image records, the viewer may also be able to zoom in on specific pieces of equipment.

Although many plants have such walk-through records, utilities vary in the extent to which they make effective use of these tools in various O&M tasks, says ENCORE's Dennis Owen. "The power of the technology already available today is really quite amazing, but the challenge of integrating it all into a viable system is tough. It's hard for plant engineers with day-to-day problems to have the luxury of time to do long-range planning. The technology can be confusing, and the demarcation between techniques and technologies is often blurred."

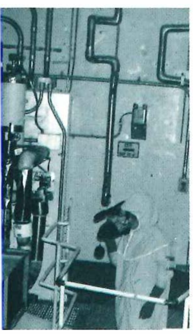
A nuclear plant that is considered a pioneer in the application of advanced imaging is Millstone, a three-unit complex in Connecticut operated by Northeast Utilities. The staff at Millstone Unit 3 has developed and deployed an integrated electronic still-video and digital imaging system for a wide variety of plant applications. Health physics personnel are the primary users of the system, but other departments, including operations, maintenance, engineering, and training, also use it. Eight professional-grade Canon and Sony still-video cameras are being used inside the plant to capture color images on magnetic microdiskettes rather than film.

The microdiskettes, about the size of a 35-mm slide, hold up to 25 high-resolution or 50 low-resolution images. The images can be displayed on a monitor or printed in color by using a disk player and printer. They can also be transferred to a computer workstation and manipulated, annotated, or enhanced to draw at-

A WEALTH OF VIDEO APPLICATIONS IN NUCLEAR POWER PLANTS

Electric utilities are using video systems in a wide spectrum of nuclear plant operations and maintenance tasks. A primary goal of many such O&M applications of video is to avoid unnecessary personnel radiation exposure.

- Monitoring of operating equipment
- Routine remote inspection
- Surveillance of maintenance work
- Monitoring of fuel-handling activities
- Fire watch during welding
- Maintenance planning and logistics
- Training of O&M personnel
- Documentation of conditions and procedures
- Surrogate plant walk-throughs
- Security surveillance
- Remote observation with robotic devices

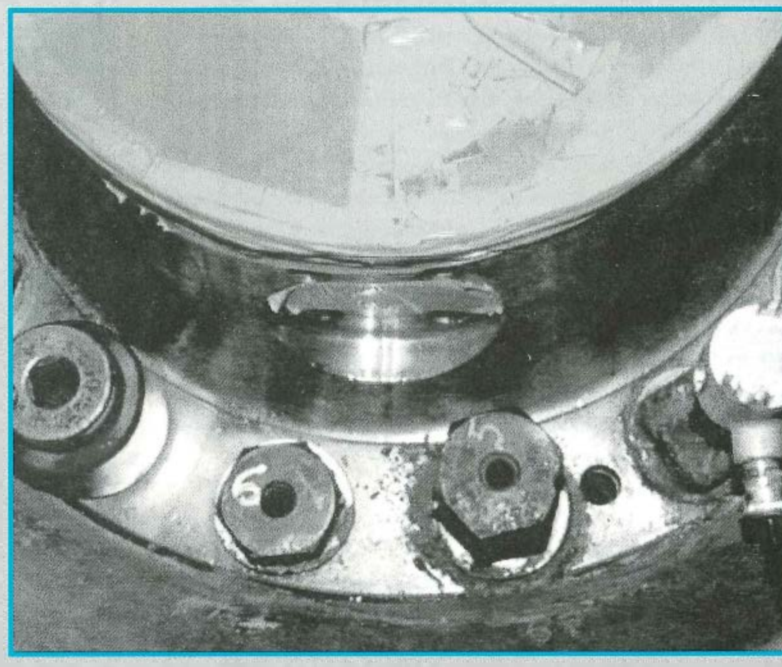


Conventional video equipment is also used at Millstone

Staff member taking still-video pictures

Still-video microdiskette

Focus on Plant O&M Applications of Video



Among the highlights of a recent EPRI survey of video camera applications in nuclear plants (NP-6882) is the extensive use of video by Carolina Power & Light at both its Brunswick twin-unit BWR plant and its Shearon Harris PWR in North Carolina. The Brunswick plant installed four cameras on the refueling floor to remotely monitor cask-loading of spent fuel channels, saving 4 person-rems by relocating crane operators to low-radiation areas. Cameras have also been used to monitor teams conducting in-vessel ultrasonic and dye penetrant examinations from the refueling floor; future teams can train by watching the job on tape.

CP&L uses 16 cameras in each of the two Brunswick turbine buildings to reduce the number of personnel entries into high-exposure areas for routine inspection and maintenance tasks. The utility reports saving between 18 and 22 person-rems through the combined use of voice communication and video supervision of operations and maintenance crews.

Health physics (HP) technicians at the Brunswick plant use cameras to assess environmental conditions and to judge protective clothing requirements. A remote radiation-monitoring system installed along with the cameras enables the HP staff to reduce the frequency of hands-on area surveys, saving the HP group an estimated 12 person-rems per year. Plant staff have noted video camera image degradation over time in high-radiation areas, mainly where gamma fields exceed 2 rads per hour.

CP&L reports that during a massive recirculation pipe replacement project, it saved 53.5 person-rems through the use of 28 video cameras, including 10 for HP coverage alone. Fixed-focus cameras were used to observe automated equipment, while remotely controlled cameras were used to monitor workers, watch for fires during welding, and provide close-up inspections of equipment and welds.

At GPU Nuclear's Oyster Creek plant, HP technicians avoided exposures of 6.4 person-rems by using multiple cameras over the course of a 13-day drywell inspection and repair project; these cameras saved other workers an additional 4.2 person-rems during the project.

System Energy Resources estimates a savings of 25 person-rems a year by eliminating human entry for routine inspection in six high-radiation areas of the turbine building at Unit 1 of its Grand Gulf plant in Mississippi. The areas are now under the quiet gaze of 23 zoom lens cameras.

At its Callaway plant, Union Electric saved an estimated 5.5 person-rems by using multiple cameras for five separate tasks during one refueling outage. The savings ranged from 0.2 person-rem for a manway removal and reinstallation to 2.8 person-rems during eddy-current testing.

The EPRI report also includes information on video applications at nuclear plants operated by Arizona Public Service, Commonwealth Edison, Duke Power, Illinois Power, the New York Power Authority, Philadelphia Electric, Public Service Electric & Gas, Rochester Gas & Electric, and the Tennessee Valley Authority. □

tention to details. Images can be combined and can be electronically pasted into documents, such as radiation survey forms, work permits, management reports, briefing sheets, and training materials. High-quality documents can be printed in full color by the laser printer. The system's images can also be transferred to videotape, laser disc, or other media.

Ronald Sachatello, radiation protection supervisor at Millstone Unit 3, says the still-video imaging system was put together on the basis of its potential to process information and reduce personnel radiation exposure. Originally the system was not able to produce high-quality documents. Working with Canon U.S.A. and one of its distributors over the past two years, Millstone added new technologies that allow for image processing and output.

The advanced imaging system, notes Sachatello, "is now used in almost all facets of plant operation. For example, on the secondary side, the cameras are used for documentation of as-found conditions. The user population has expanded to where the engineering, mechanical, security, and training people check out cameras and go shoot their subjects, and we process the images for them into different formats and types of output.

"We have all the other typical industrial video equipment—camcorders, 35-mm equipment, and Polaroids—but none has the flexibility, quality, and turnaround capabilities of the still-video system. The beauty of still-video is that we can take a camera inside the reactor containment at full power, take a series of pictures, and within a few minutes of exiting containment have everything blown up, annotated, printed, and in the hands of plant management."

Sachatello says the computer workstation that is part of the still-video system gives the plant high-quality desktop publishing capability for generating all types of reports. The images can even be transmitted to utility engineering offices over a computer network or via modem to a contractor with an appropriate receiver-processor thousands of miles away. "We're looking into integrating this technology into our procedures manuals and training materials," he says, "since it has the ability to add color pictures and make publications as user-friendly as possible. We're already producing briefing sheets, training manuals, and reference books with images and text that are of textbook quality."

Besides the sharper, more useful publications, dramatic benefits in avoided radiation exposure have also been realized at the 1150-MW Unit 3 PWR. A commitment by station management to reducing exposure, coupled with innovative technologies such as the imaging system, has led to a decline in annual radiation exposure from a seven-year average of about 140 person-rems to 11.8 person-rems in 1990 at Millstone Unit 3. "We attribute a lot of this improvement to a proactive station management willing to integrate innovative technologies on all fronts," says Sachatello. "The imaging system is a good example of management support for technological solutions to complicated system repair and maintenance requirements."

The still-video system is now also being used by personnel at Units 1 and 2 at Millstone, and the staff is setting up a similar system at the Seabrook nuclear plant in Massachusetts. The Connecticut Yankee nuclear plant also has one.

EPRI looks ahead

As EPRI's O'Brien explains, video and advanced imaging technology are becoming firmly entrenched in a broad range of industrial and commercial applications, including nuclear power, which will quite likely ensure a continued stream of technical and product development, much of it application-specific. So rather than conducting technology development, research managers say, a more likely near-term role for EPRI is communicating applications experience to the utility industry and perhaps developing applications-oriented training.

"We want to package a number of things we've been doing—the video survey, the work on still-video and imaging, some work we've done in infrared thermography images of plant equipment—into some sort of seminar, perhaps involving hands-on training at the Nondestructive Evaluation Center," says O'Brien. "Beyond that, one possible area for investigation suggested to us is the issue of utilities accumulating vast image collections that begin to pose problems of indexing and retrieval. Maybe there is an opportunity to make a contribution there.

"Eventually, people envision being able to link digital images directly into CAD/CAM systems as input to 3-D models of plant areas. We're interested in the potential of 3-D modeling to map all the hazards in a workplace and, with animation, to depict the different jobs being performed and suggest ways to do them with reduced exposure to hazards. With such a system, we would be able to integrate everything we know about a maintenance task and refine and practice its execution without entering radiation zones at all. It sounds futuristic, but that's the vision." ■

Further reading

Advanced Imaging Tools and Their Applications for Nuclear Power Plant Operation and Maintenance. Final report for RP2705-14, prepared by ENCORE Technical Resources, Inc. December 1991. EPRI TR-100165.

Dennis Owen and John O'Brien. "The Age of the 'Throwaway' Video Camera." *Nuclear Engineering International*, Vol. 36, No. 442 (May 1991), pp. 36–37.

Video Camera Use at Nuclear Power Plants. Final report for RP2705-13, prepared by ENCORE Technical Resources, Inc. August 1990. EPRI NP-6882.

Maintenance of Video Cameras in a Contaminated Environment. EPRI Technical Brief TB.NPD.38.8.87.

Radiation Protection Management Program at TMI-2: Noteworthy Practices and Accomplishments. Final report for RP2558-2, prepared by Pentek, Inc. August 1987. EPRI NP-5338.

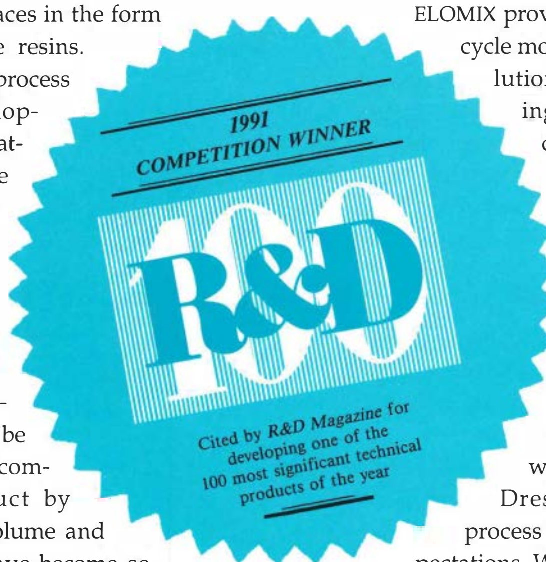
Video Cameras for TMI-2 In-Containment Tasks. EPRI Technical Brief TB.NPD.14.10.85.

This article was written by Taylor Moore. Background information was provided by John O'Brien, Nuclear Power Division.

TECH TRANSFER NEWS

Improved Decontamination Process Cuts Waste Volume

EPRI's LOMI (low-oxidation-state metal ion) decontamination process has become the preferred approach at nearly all U.S. nuclear power plants for removing corrosion films from reactor coolant system surfaces: the process has been used in 90% of all such jobs undertaken since 1985. A significant part of the 50% reduction in personnel radiation exposure since 1984 can be attributed to LOMI's role in removing radioactive isotopes from surfaces in the form of ion-exchange resins.



Now a new process is under development that dramatically reduces the volume of radioactive waste generated by LOMI. It has been licensed to Westinghouse Electric Corporation and could be available as a commercial product by 1993. "Waste volume and disposal cost have become serious impediments to the increased use of chemical decontamination on a routine basis at nuclear plants," says Chris Wood, a senior program manager in EPRI's Nuclear Power Division. The new process—dubbed ELOMIX (electrochemical LOMI ion exchange)—has been shown to cut waste generation during chemical decontamination by a factor of 10 or more. The savings in disposal costs for a typical job could be about $50,000.

ELOMIX recently earned Wood his third R&D 100 Award from *Research & Development Magazine.* His work on the original LOMI process was similarly honored in 1983.

In conjunction with the LOMI decontamination method, ELOMIX uses an electrochemical cell to continuously remove radioactive ions, mainly cobalt-60, from the ion-exchange resin. The ions are removed as metallic residue on a filter that can be stored in a shielded container for later disposal. The nonradioactive resin solution is replenished and returned to the reactor coolant system to dissolve more corrosion film. The concentrated metallic residue from the new process is inert and stable, whereas contaminated ion-exchange resins are organic and require stabilization, generally in cement. ELOMIX provides a way to recycle most of the resin solution while minimizing the amount of contaminated waste requiring disposal.

In the first small-scale demonstration of the ELOMIX process, conducted at Commonwealth Edison's Dresden plant, the process exceeded test expectations. Wood says that, in principle, the technique could be used for all radioactive process solutions, including those from steam generator cleaning and those from mixed-waste processing. There are also potential nonnuclear applications in metals recovery and hazardous waste processing.

ELOMIX was developed for EPRI by Bradtec Limited. Final field testing and demonstration of the process should begin early next year, with commercial availability expected about a year later. ■ *EPRI Contact: Chris Wood, (415) 855-2379*

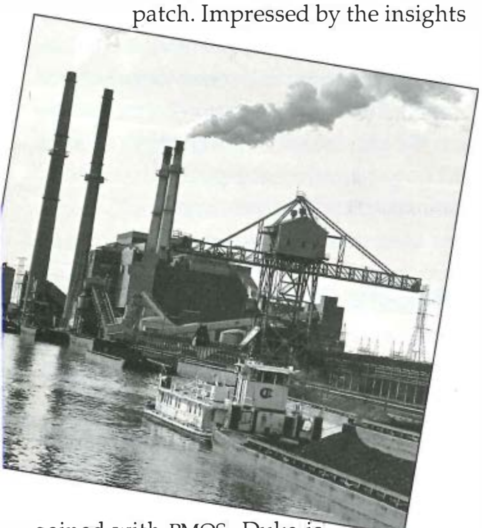
New Software Evaluates Plant Modifications

In planning for the conversion of aging baseload fossil fuel power plants to cycling duty, utilities are trying to improve unit performance and reduce operating costs through a variety of equipment changes, the dynamic effects of which are difficult to assess in advance. Conventional methods for evaluating plant modifications are data- and computation-intensive, lack sufficient resolution for small, subtle changes, and may not fully account for savings from changes in unit commitment and dispatch.

As part of its fossil plant upgrading program, Duke Power recently used an EPRI computer model now in the final stages of development to evaluate various changes. The utility estimates that with help from the PMOS (plant modification operating savings) model, it saved over $2.5 million by identifying cost-effective modifications, canceling uneconomic ones, and deferring those expected to be only marginally cost-effective. "The PMOS model enhanced our understanding of the economics of proposed modifications and the potential changes in unit operation," says Duke's Clyde Hatley.

A team from Duke, EPRI, and Decision Focus Incorporated (which developed the model for EPRI) used PMOS in evaluating the expected operating cost reductions of seven proposed fossil plant upgrades and a low-load modification. On the basis of the model's results, Duke installed a variable-speed induced-draft fan at one unit but canceled fan installation at two other units, for capital cost savings of $1.5 million. Reduced operating costs and lower heat rates at low loads—also achieved through modifications evaluated with PMOS—accounted for the rest of the estimated savings.

Given a power plant's cost and performance characteristics and the marginal energy costs for a system, the easy-to-use PMOS software uses dynamic programming to determine, for each hour, the loading at which the modified plant should operate. It calculates both direct savings due to heat rate reductions and indirect savings from changes in unit dispatch. Impressed by the insights gained with PMOS, Duke is planning to use it to evaluate other proposed plant modifications.



"EPRI's PMOS model can be used by utilities to get essential information needed for evaluating baseload-to-cycling unit conversions," says David O'Connor, a project manager in the Generation and Storage Division. "PMOS can also be used to evaluate noncycling modifications, such as heat rate improvement programs." The software, now in beta testing at several other utilities, is expected to be available to all EPRI members early in 1992. ■ *EPRI Contact: David O'Connor, (415) 855-8970*

Freeze Concentration Dairy Process Saves Energy

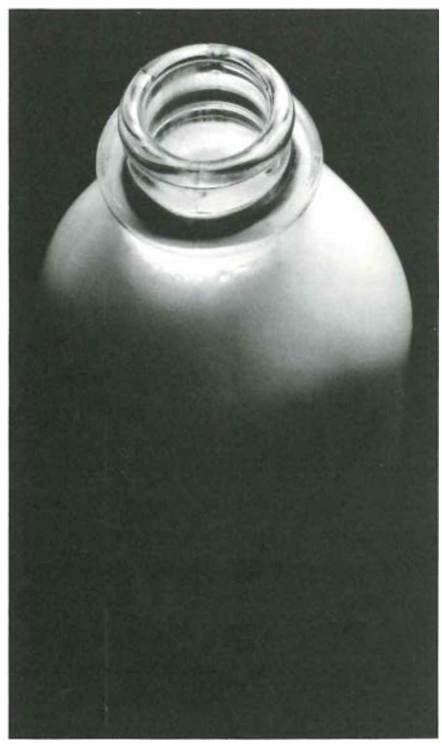
Initial results are expected next year from a commercial demonstration of an EPRI-patented freeze method for concentrating dairy products that uses half the energy of conventional evaporation and promises new rich-tasting but low-fat milk, cheese, and ice cream products. By removing water as ice crystals, the new process not only requires substantially less energy than heat-based evaporative methods but also preserves the original protein structure that gives dairy products taste, texture, and aroma.

With cofunding from EPRI, the Dairy Research Foundation is managing the 30-month, $2.8 million demonstration of the process at Galloway West Company, a dairy processor in Fond du Lac, Wisconsin. Sponsors also include the U.S. Department of Energy and the process developer and equipment manufacturer, Grenco Process Technology of the Netherlands. Wisconsin Power & Light, which serves half of the state's dairy farms, provided equipment to monitor the energy efficiency of the pilot-scale concentration unit, which can remove 800 pounds of water per hour.

Freeze concentration is already widely used to produce frozen orange juice concentrate, and it looks promising for dairies, which, of all food processors, use the most energy for product concentration. A multistage evaporator uses the energy equivalent of about 118 kWh for every metric ton of water removed from dairy products, while multistage freeze concentration uses 65 kWh per ton. Replacing a full-scale, 50,000-pound-per-hour evaporator might save a dairy approximately $100,000 a year in energy costs. Additional savings could result from the recovery of product now lost in cleaning evaporator equipment, and from the longer shelf life and lower shipping costs that are possible with freeze-concentrated dairy products.

The process may provide a high-quality source of protein from whey, as well as new fat- and lactose-free products. Unlike evaporative methods, it does not change the protein structure that is key to the taste and texture of dairy products. Thus, freeze-concentrated nonfat skim milk has the richer taste of low-fat or whole milk. "We may be able to relate the process to ice cream, cheeses, spreadable dairy products—products we can't imagine yet," says Salah Ahmed, technical director of the Dairy Research Foundation. "We may be able to make nonfat ice cream that tastes like the real thing."

Ammi Amarnath, a senior project manager in the Industrial Program of EPRI's Customer Systems Division, says freeze concentration processes similar in principle to the one being evaluated in Wisconsin for dairies could be applied in the treatment of industrial wastewater and in the chemical and petrochemical industries. ■ *EPRI Contact: Ammi Amarnath, (415) 855-2548*



Exploratory Research

Improving Fossil Fuel Combustion Processes

by John Maulbetsch, Office of Exploratory and Applied Research

Fossil fuel combustion processes generate more than 70% of the electricity produced by electric utilities in the United States. EPRI is sponsoring exploratory research to identify innovative ways to manipulate these processes in order to improve overall power plant performance. The research is characterizing relationships between fuel properties, combustion chemistry, and combustion fluid dynamics and identifying the effects of these relationships on combustion efficiency and the formation of nitrogen oxides (NO_x) and particulates. Results have been promising in several areas of investigation: the use of acoustic waves to reduce NO_x formation in coal burners, the design of a low-NO_x burner for oil- and gas-fired boilers, the development of a coking indicator for fuel oils, and research on the relationships between coal quality and combustion performance.

Acoustic forcing to reduce NO_x

Exploratory research at Stanford University is seeking to improve understanding of the fundamental chemical and fluid dynamics mechanisms that control NO_x formation in coal burner flames (RP8005-2). Using this knowledge, the researchers plan to develop an aerodynamic approach to NO_x control. In the first phase of the project, cold-flow visualization studies were conducted to investigate fluid dynamics in coal burners, and a bench-scale combustor was used to study NO_x formation mechanisms during the early stages of combustion.

The flow visualization studies used a jet of particles entering quiescent air to simulate pulverized-coal injection by burner nozzles. The particles naturally aggregated into dense clouds on the mushroom-like caps of shear-layer vortices. These clouds were then ejected into the surrounding air in bursts. Using acoustic waves, the researchers were able to manipulate the position of the vortices and thus control the agglomeration of particles into clouds and the location of their eventual ejection.

The combustor studies examined in detail how the mixing of gaseous hydrocarbon fuel compounds, combustion products, and oxygen affects NO_x formation and carbon burnout. In coal burners, rapid mixing results in a stable, intense flame that optimizes combustion intensity and carbon burnout. But this type of flame also promotes NO_x formation.

During the devolatilization/pyrolysis stage of combustion, much of the nitrogen in coal particles (fuel nitrogen) is released and is incorporated into tars and light gases. Tests revealed that the fate of this nitrogen is more sensitive to the presence of oxygen than was previously known. If oxygen is present, a significant amount of the nitrogen is converted to NO_x; but in oxygen-deficient regions, such as dense clouds of coal particles, most of it is converted to molecular nitrogen (N_2).

Using the results of the flow visualization and combustor experiments, the Stanford researchers are now attempting to develop a satisfactory compromise between combustion intensity and NO_x formation. They are studying the use of subharmonic acoustic forcing to delay dispersion of coal particle clouds into the surrounding combustion air until devolatilization and pyrolysis are essentially complete and the majority of nitrogen has been converted to N_2.

To determine the efficacy of this method under combustion conditions, the flow visualization apparatus has been modified to simulate swirling and pumping flows and other disturbances that could overwhelm forcing mecha-

ABSTRACT *By providing a better fundamental understanding of fossil fuel combustion processes, EPRI-sponsored exploratory research aims to identify new ways to boost fuel conversion efficiency and reduce emissions of unwanted by-products, such as nitrogen oxides and particulates. The research is focusing on relationships between fuel properties, combustion chemistry, and combustion fluid dynamics. Judging from the results to date, these efforts promise to lead to the development of new combustor designs and operating approaches that increase fuel flexibility and reduce emissions.*

nisms in typical boilers. Once the researchers have developed a forcing scheme that can suitably control particle dispersion, they will test it in the combustor, which has been reconfigured to accommodate an acoustic driver. Vortex pairing and the distance before abrupt dispersal of the coal particles will be correlated with carbon burnout and NO_x control performance to identify an optimal forcing scheme.

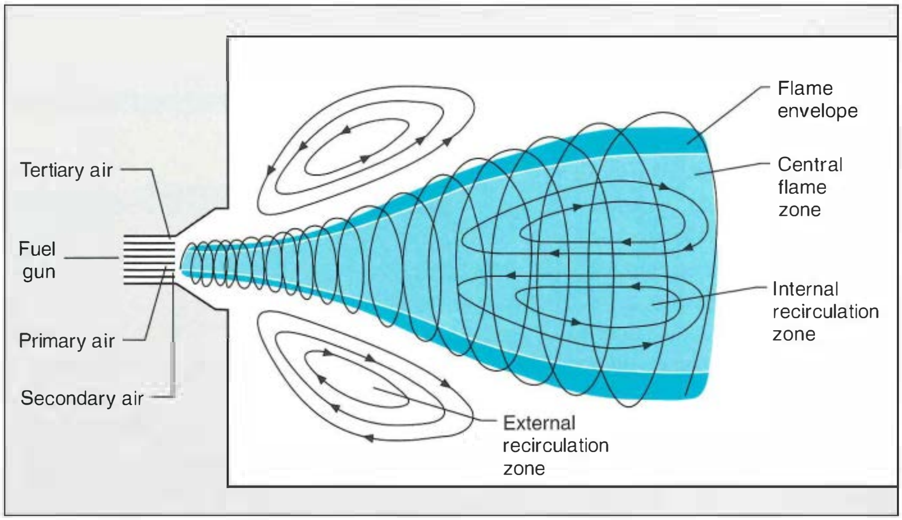
By using a mathematical model, the researchers have already shown that the installation of acoustic drivers in coal burners will not require structural boiler modifications, and that the drivers will not affect boiler operation if their subharmonic waves are operated out of phase. In pulverized-coal-fired plants, this forcing approach could reduce NO_x emissions to one-third the current standard (which is 0.5–0.6 pound of NO_x per million Btu) for \$3–\$5 per kW, with minimal operating costs and no reduction in carbon burnout. Its successful implementation would obviate the need for postcombustion catalytic reduction systems, which cost \$50–\$75 per kW in new plants and have higher operating costs.

Low-NO_x burner for oil and gas

Scientists at the Massachusetts Institute of Technology who are studying the fundamental characteristics of low-NO_x burners for oil- and gas-fired boilers have developed a novel design that could provide greater NO_x emissions reductions than possible with existing options (RP8005-9). The new design, called a radially stratified flame core burner, consists of a central fuel gun surrounded by three annular air nozzles that radiate out from the central core. Airflow and the degree of air swirl are controlled independently in the three annuli, permitting precise control of fuel-air mixing characteristics.

The MIT Combustion Research Facility identified the parameters that determine the burner's NO_x control performance—fuel jet velocity and angle, axial fuel gun position, primary air fraction, and swirl pattern. Then the researchers conducted a detailed flame characterization study using the values of these parameters that produce a flame with the lowest NO_x emissions. A major fraction of the air-

Figure 1 Configuration of the low-NO_x flame produced by the new radially stratified flame core burner for oil- and gas-fired boilers. The air swirl pattern created by the burner promotes staged combustion and suppresses NO_x formation.



flow for this flame enters through the secondary air port, with the remainder being equally divided between the primary and tertiary air supplies. The resulting swirl pattern in the combustion air is characterized by solid-body rotation in the flame core and a swirl rate that declines radially to zero beyond this core.

This pattern produces a density gradient and flow field that stratify the flame through dampened turbulence at the interface between the central flame zone and the surrounding airflow. As a result, combustion is staged: near the fuel gun, fuel-air mixing is suppressed; farther downstream, the toroidal recirculating flow promotes mixing (Figure 1). NO_x formation is reduced because the more gradual mixing of fuel and air results in a lower flame temperature and because less oxygen is available to react with any fuel nitrogen released early in combustion.

In preliminary testing using preheated (450°C) combustion air and 1% excess oxygen, NO_x emissions as low as 70, 54, and 97 ppm were obtained for natural gas, No. 2 fuel oil, and No. 6 fuel oil, respectively. Additional reductions (to 15 ppm) were achieved for natural gas by using flue gas recirculation through the burner and a new method of injecting small amounts of steam. Future work will try to optimize these techniques.

This work is cosponsored by ESEERCO, Florida Power & Light, Southern California Edison, and Southern California Gas, as well as by ENEL and Eniricerche of Italy.

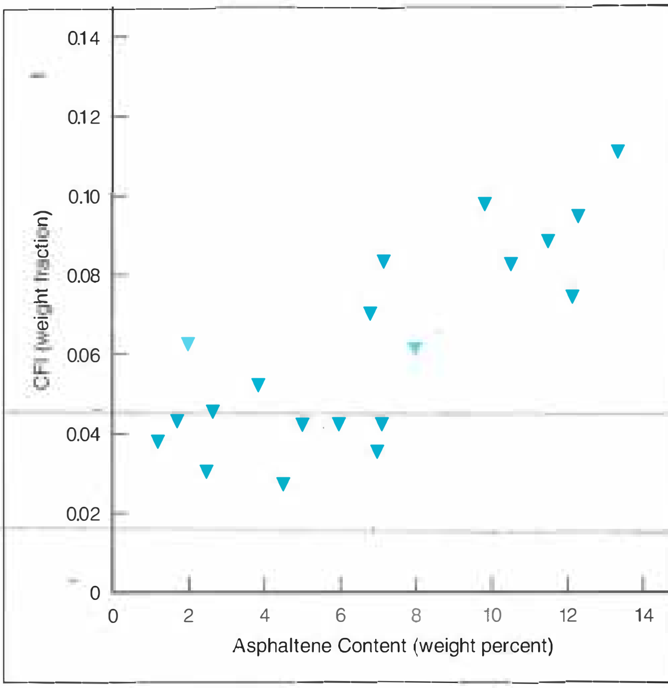
Fuel oil properties and coke formation/oxidation

The Fuels Research Group at Princeton University is examining the fundamental relationships between heavy fuel oil properties and the formation and subsequent oxidation of carbonaceous residues produced during the combustion of these oils (RP8005-1). The formation of large quantities of these residues, known as cenospheric coke particles, is a primary problem in heavy fuel oil combustion. If these high-carbon-content particles do not oxidize fully, fuel conversion efficiency decreases and particulate emissions increase. In addition, the particles may adhere to convection tube surfaces, reducing heat transfer and accelerating tube corrosion. The decreasing quality and high variability of heavy fuel oils complicate efforts to identify combustion processes that avoid these problems.

This work aims to elucidate the effects of fuel composition on the formation and destruction of coke particles during combustion. Engineering models will use this information, along with information on how burner and boiler characteristics affect particulate emissions, to identify the optimal combustion process for a particular fuel.

Using an isolated-droplet combustion apparatus, the Princeton researchers have developed the coke formation index (CFI), which indicates the amount of coke formed per unit mass of a particular fuel oil, independent of combustor design and operating factors. Particles produced by burning individual fuel oil droplets are collected at the precise moment that particle formation is complete (i.e., the vapor-phase burnout point). They are then counted and weighed to determine average particle mass. Dividing this quantity by the initial droplet mass yields the fuel's CFI. In analyses of 26 fuels, the researchers have shown that CFI is a repeatable coking indicator that depends primarily on fuel properties and is relatively independent of droplet size and combustion conditions.

Figure 2 Coke formation index (CFI) versus asphaltene content for 20 heavy fuel oils. Note that oils with similar asphaltene contents were found to differ as much as 100% in CFI. For some oils, not all the asphaltene was converted to coke; for others, nonasphaltene constituents were converted to coke. These results demonstrate that asphaltene content is a less accurate coking indicator than CFI.



With the index, the size distribution of the coke particles that will form during combustion of a particular fuel oil can be predicted on the basis of fuel droplet size. Heavy fuel oils are typically introduced to combustion flames by spray nozzles that produce a wide range of droplet sizes. If the relative fraction of each droplet size within this range is known, it is possible to predict the coke particle diameter distribution.

The CFI technique simulates boiler conditions more accurately than other coke formation tests, provides information about particle structure, and—unlike various asphaltene tests—represents an actual coke measurement (Figure 2). Further, it produces nascent coke cenospheres for use in studies to define particle burnout parameters.

The researchers are currently investigating coke particle oxidation in an apparatus with a dilute fluidized bed. They are studying fundamental kinetic parameters, combustion chemistry, particle morphology, and particle ash components in order to clarify cenospheric coke burnout. Results indicate, for example, that particles with higher concentrations of such oxidation catalysts as vanadium, nickel, and iron have higher combustion rates.

Coal quality and combustion performance

At Sandia National Laboratories, researchers are studying relationships between coal quality and the combustion reactivity and burnout behavior of coal chars (RP8005-3). Fundamental information from this study will become part of a database EPRI is developing on the impact of coal quality on the performance of existing or new pulverized-coal-fired plants. The database will help utilities assess coal-cleaning, -switching, and -blending options.

In the first phase of the project, two high-volatile bituminous coals (Kentucky No. 9 and Pittsburgh No. 8) and their medium- and deep-cleaned products were examined in high-temperature bench-scale flow reactors equipped with advanced, in situ optical diagnostics. Rates of char oxidation were determined for the coals as a function of the extent of cleaning and char burnout.

Results indicate that cleaning influences the overall burning rate of coal chars: raw coal burns fastest, and deep-cleaned coal burns slowest. Raw coals have a higher ash content and a lower carbon content and therefore reach burnout more quickly. However, coal cleaning does not affect the temperature dependence of the overall burning rate.

These experiments have also yielded the burning rates of individual coal particles. Considerable variations in rate were observed for particles that were approximately the same size but differed in ash content. The researchers hypothesize that this phenomenon reflects the impact of ash content on effective emissivity, especially during the late stages of burnoff. As a particle burns, ash content increases, decreasing effective emissivity and the rate of radiative heat loss. As a result, both particle temperature and burning rate are higher for particles with a higher ash content. A better understanding of the influence of ash and maceral content on combustion processes is necessary for predicting the final stages of burnoff.

The second phase of this project is examining the combustion kinetics of 12 coals. The objectives are to determine reactivities for the coals and to investigate causative factors, such as ash and maceral content, for reactivity variations. If differences in the reactivities of coal constituents contribute to unburned carbon, then the characterization of the combustion behavior of reactive and unreactive coals could lead to the identification of boiler conditions that produce higher carbon conversion.

In summary, these four exploratory research projects illustrate how an improved understanding of fundamental mechanisms, even for technologies as well developed as fossil fuel combustion, can help improve process control. Future work will continue to explore innovative combustion control techniques to minimize NO_x formation while maintaining complete carbon burnout.

EPRI's exploratory research draws on technical expertise from throughout the Institute. Angelos Kokkinos, Arun Mehta, George Offen, and William Rovesti of the Generation and Storage Division manage the projects described here and provided much of the information for the article.

Residential Program

Field Testing of the HydroTech 2000 Heat Pump

by John Kesselring and Arvo Lannus, Customer Systems Division

An advanced heat pump system developed by EPRI and Carrier Corporation under RP2033-1 integrates water heating with space heating and cooling. Called the HydroTech 2000™, this system is designed to provide good comfort control, quiet performance, and high space-heating, space-cooling, dehumidification, and water-heating efficiencies. (These high efficiencies respond to the need for global climate protection.) The HydroTech 2000 is very competitive with nonelectric space-conditioning and water-heating appliances and can help electric utilities maintain or expand market share. In addition, its variable-speed operation spreads load more evenly over daily cycles and can help utilities reduce their peak loads. Further, the system is designed for easy implementation of utility load management options.

System design

The HydroTech 2000 heat pump system has three major components—an outdoor fan-coil unit, an indoor variable-speed compressor unit, and an indoor variable-speed fan-coil unit—as well as a standard electric water heater.

The outdoor unit contains a high-efficiency refrigerant coil with a single-speed fan and motor. In the space-cooling mode, heat is transferred from the refrigerant to the outside air; in the space-heating mode, cold refrigerant in the coil is evaporated to absorb heat from the outside air.

The compressor unit contains the system's control and drive electronics as well as a high-efficiency variable-speed compressor; a refrigerant-to-water, tube-in-tube heat exchanger; and a small pump. Microprocessors control all heat pump functions, including variable-speed operation, water heating, energy-saving demand-only defrosting, and automatic troubleshooting in case of malfunction. A programmable electronic thermostat performs temperature-setting and scheduling functions and can be interfaced with a duct-damper control system or the touchscreen of a home automation system, if desired.

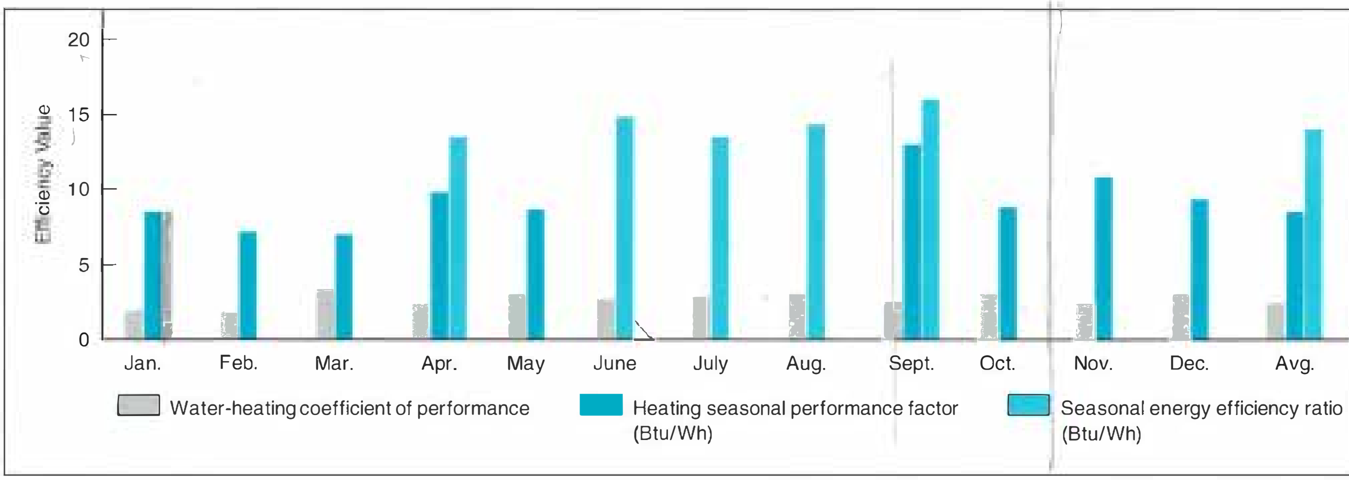
The indoor fan-coil section connects to the house ductwork. Refrigerant circulating in the coil either heats the indoor air or cools and dehumidifies it. A variable-speed fan, electronically linked to the compressor, increases or decreases speed to match the heating or cooling load.

Under normal circumstances, the heat pump has sufficient capacity to heat water while it heats or cools the indoor air. In the combined space-cooling and water-heating mode, the heat pump uses heat rejected from the home interior to meet most of the hot water requirements. In the combined space-heating and water-heating mode, compressor speed and capacity are increased to enable the system to perform both functions. On days when the system's full capacity is required for space heating, electronic controls switch on a conventional electric resistance element in the hot water tank. When only water heating is required, the HydroTech 2000 operates as an air-to-water heat pump, transferring heat from the outside air to the water.

The compressor and the indoor fan use

ABSTRACT *EPRI and Carrier Corporation have developed an advanced residential air-source heat pump system that meets the consumer's need for improved efficiency and comfort while reducing utility peak loads. Commercially available since 1990, the system integrates efficient space conditioning with domestic water heating. Ongoing field tests show that the system, which incorporates electronically controlled variable-speed drives, has very high space-cooling, space-heating, and water-heating efficiencies and offers substantial energy cost savings in most U.S. climates.*

Figure 1 Efficiencies of the 2-ton HydroTech 2000 unit for water heating, space heating, and space cooling at the Syracuse, New York, test site during 1990. Results from ongoing field tests in a variety of climates are confirming the heat pump system's high overall efficiency.



electronically commutated permanent-magnet motors to match operating speed to thermal load requirements. A diode rectifier converts ac power into three-phase dc, which an inverter bridge converts to pulses that permit adjustment of the motor speed. This load-matching capability, which avoids on-off cycling, is responsible for most of the efficiency improvement offered by the heat pump. Variable-speed operation also provides significantly better temperature and humidity control than is provided by conventional, single-speed heat pumps, and it helps minimize the phenomenon called cold blow—that is, the delivery of cold air upon fan startup. The use of heat from the water tank to defrost the outdoor coil (with the indoor fan in the off position) speeds up defrost cycles and eliminates the use of resistance heating, which is necessary to balance the cooling effect of a conventional heat pump during defrosting.

Carrier currently produces the HydroTech 2000 heat pump in 2-ton and 3-ton capacities, with the larger unit being slightly more efficient. On the basis of laboratory measurements and the U.S. Department of Energy's standard rating procedure, the 3-ton model attains a seasonal energy efficiency ratio (SEER)—a measure of cooling efficiency—of 14.05 Btu/Wh and a heating seasonal performance factor (HSPF) of 9.05 Btu/Wh; the 2-ton model attains a SEER of 13.35 and an HSPF of 8.75. Moreover, the heat pump system usually eliminates supplemental electric resistance water heating on all but the coldest days: on average, the heat pump has met about 80% of the annual hot water requirements in homes in the test program. When the water-heating energy savings are accounted for, the performance of the 3-ton HydroTech 2000 unit is equivalent to a SEER of 21 and an HSPF of 11, making it the most efficient space-conditioning and water-heating system available.

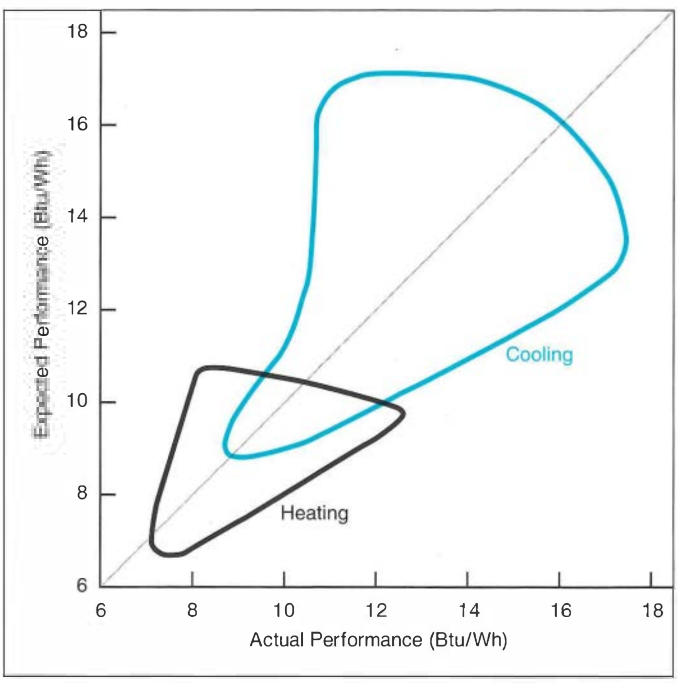


Figure 2 A comparison of expected and actual space-conditioning performance for the HydroTech heat pump at 23 field sites in 1990–1991 revealed these patterns of data scatter. Differences between assumed and actual indoor thermostat settings accounted for most of the variation in correlation.

Field test results

In ongoing EPRI-supported testing at 30 homes in 17 states, Carrier is monitoring the performance of the heat pump system. Test sites are located in several major urban areas (as well as some rural areas) and in several climate zones. At each test home, Carrier installed a HydroTech 2000 system, along with monitoring equipment and a personal computer linked via phone lines to both a central PC, used for daily reviews, and a mainframe computer, used for archiving and monthly data analysis.

The field test results provide clear information on the heat pump's performance in various climates. Figure 1 shows the monthly system efficiencies of a 2-ton unit in Syracuse, New York, for 1990. In this northerly climate, heat is used during nine months of the year (September–May). On average, the system attained a SEER of 14.1, an HSPF of 8.4, and a water-heating coefficient of performance (COP) of 2.3. This high COP contributed significantly to the overall efficiency of the unit. A conventional electric water heater has an energy factor of 0.88; hence the HydroTech 2000 was 2.6 times more efficient in heating water at the Syracuse site.

Figure 2 presents the results of a comparison of actual system heating and cooling performance with expected performance for 23 of the field test sites. The expected HSPF and SEER values are based on average local weather conditions and assume indoor thermostat settings of 70°F for heating and 80°F for cooling. Most of the deviation of data from the line indicating perfect correlation is due to occupant lifestyle. Only five of the test homes had thermostat settings of 80°F or higher for cooling; the actual settings ranged as low as 73°F. Thermostat heating settings varied between 65° and 76°F. In nearly all cases, the thermostat setting could be directly correlated with the difference between actual and expected performance. Other reasons for data scatter include weather that departed from long-term averages, over- or undersized heat pump systems, and variations in building construction.

The amount of water heating done by the heat pump varies with location. For the Syracuse site, an analysis of the 1990 data on the water-heating contributions of the heat pump and the electric resistance water heater found that only in the relatively cold month of February did the heat pump's contribution fall below 75%; its average monthly contribution was about 84%. At a site in Phoenix, Arizona, high groundwater temperatures and extensive waste heat recovery from space cooling allowed the heat pump to supply all the hot water needed throughout the year.

The HydroTech 2000's ability to minimize peak power demand is illustrated in Figure 3, which presents the distribution of compressor operating speeds for a test site in Indiana. The unit runs at low speed most of the time, especially during the summer months. Not only does this pattern of operation result in high system efficiency; it also means that power demand is low when demand is of most concern to the local utility—which, like most U.S. utilities, is summer-peaking.

The testing has confirmed that the HydroTech 2000 system operates at lower sound levels than any comparable heat pump. Outdoor sound ratings were in the range of 6.6 to 7 bels (the level of quiet to normal conversation). Thus the system is substantially quieter than typical outdoor units, which have a sound level of 7.8 to 8 bels (comparable to that of a vacuum cleaner). Indoor sound ratings did not exceed 6.6 bels, meaning that the compressor unit creates no more noise than a normal household refrigerator.

Ongoing research

When the HydroTech 2000 was first introduced, no government-approved rating method was available for estimating the operating costs and coefficients of performance for integrated space-conditioning and water-heating systems. Under RP2033-26, the National Institute of Standards and Technology developed a methodology for rating integrated air-source heat pumps, a methodology designed to facilitate the comparison of systems on the basis of overall efficiency. Subsequent EPRI research has emphasized labora-

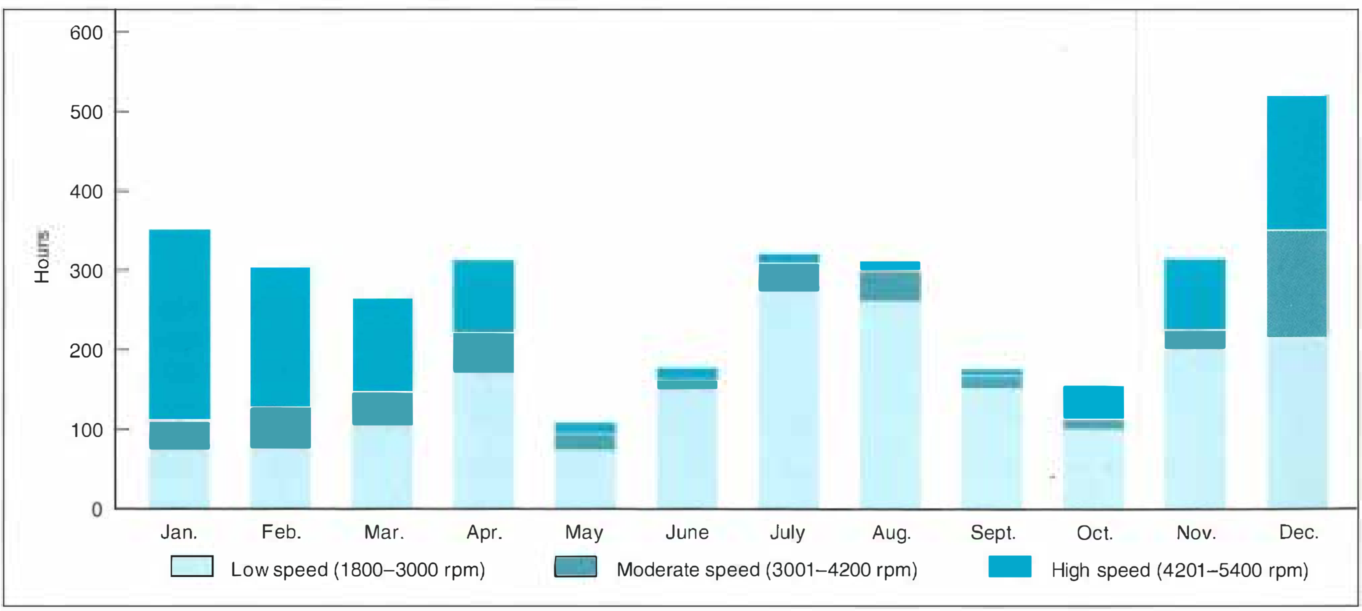


Figure 3 Compressor-operating-speed distribution for a HydroTech unit at an Indiana (Indianapolis) test site in 1990. The system's ability to match operating speed to thermal load requirements results in efficient performance and can also help minimize utility peak demand. Note that during the summer, when the utility experiences its peak, the compressor runs at low speed (i.e., has low power demand) most of the time.

tory testing to obtain the performance data necessary for approval of a final rating methodology; the results will be released soon.

EPRI continues to work with Carrier to improve and upgrade the HydroTech 2000 system hardware, and it is also funding other efforts to develop cost-effective heat pumps. Field testing of a single-package, dual-fuel heat pump being produced and marketed by Goodman Manufacturing Company is being carried out under RP2868-2. With support from both EPRI (RP2892-7) and Mississippi Power Company, Water-Furnace, Inc., is developing a two-speed water-to-air heat pump to provide efficient space heating and cooling and year-round water heating (which, in the air conditioning mode, makes use of rejected heat). The two-speed feature allows the heat pump to be sized for a large heating load without being oversized for the cooling load and thus permits good humidity control. In another effort (RP2892-19), Nordyne, Inc., is developing an efficient, cost-effective single-speed heat pump with year-round water-heating capability for the conventional and manufactured (i.e., mobile home) residential housing markets.

Nuclear Component Reliability

Underwater Welding for Pressure Vessel Repairs

by Wylie Childs, Nuclear Power Division

ABSTRACT *Repairing the internal components of reactor pressure vessels may call for effective underwater wet-welding techniques. A manual process, shielded metal arc welding (SMAW), is already in use but has some limitations, particularly in the largely inaccessible lower portions of the reactor vessel. Using specially constructed test tanks, an EPRI program is developing welding procedures for performing successful underwater repairs. The tests have achieved high-quality welds on Type 304 stainless steel with SMAW and also with flux-core arc welding, an automated process that allows remote repairs in limited-access areas.*

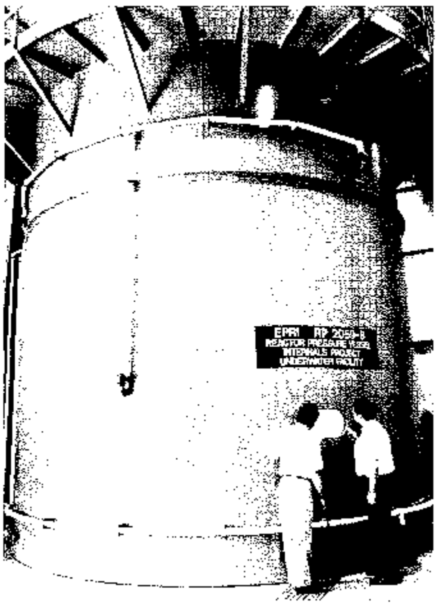
In response to member utility concerns, EPRI initiated a program to improve the inspection and repair of reactor pressure vessel internal components (RPC103-1). Reactor internals are fabricated primarily from stainless steel and nickel-base alloys, which may be susceptible to intergranular stress corrosion cracking in some LWR environments.

Underwater wet welding is not new to the nuclear power industry. In fact, utilities have performed wet-welding repairs on steam dryers, moisture separators, feedwater sparger nozzles, and core spray headers. To date, diver-welders have used the shielded metal arc welding (SMAW) process for all in-vessel underwater wet-welding repairs. These repairs have been in the upper regions of the reactor pressure vessel, which have relatively low radiation levels, offer water shielding, and provide generally unobstructed access for diver-welders. In locations where access is limited, an automated remote process is the only logical choice for performing repairs.

A major objective of the EPRI research is to understand and improve existing technology for underwater wet welding, which is based principally on offshore experience. Manual SMAW is the most common process for underwater wet-welding applications. Defects such as porosity and lack of fusion are typical in these applications because of the fast freezing of the weld puddle. Therefore, one program goal is to develop improved techniques and, if necessary, improved filler materials, or consumables, to address these problems. To support this effort, facilities were constructed for testing underwater welding processes. These facilities include a small test tank, with a working depth of 4 feet, and a larger, 20-foot-diameter test tank that is 22 feet deep (Figure 1).

The manual SMAW process was used in a series of tests that featured conventional 308L stainless steel consumable electrodes and EPRI-developed waterproof-coating techniques (Figure 2). These electrodes provided sound welds with good penetration, representing a significant improvement over welds produced with commercially available underwater electrodes. In addition to the use of waterproof electrode coatings, another key to obtaining high-quality underwater SMAW welds with excellent bead appearance and penetration was the use of pulsed current.

Figure 1 This 22-foot-deep tank was built to evaluate welding techniques (both manual and automated) for underwater applications such as in-vessel repairs at nuclear plants. Testing to date has used stainless steel electrodes and EPRI-developed waterproof-coating techniques.



Automated underwater welding

Although manual techniques are suitable for many underwater welding repairs, locations with limited access and/or high radiation levels require automated welding processes. Such locations include, for example, the lower two-thirds of the reactor pressure vessel, where access is severely restricted and remotely operated equipment is necessary.

A survey to determine past applications of underwater remote welding found that most automated-welding development work had entailed the use of a water-free, dry enclosure. Some experience with flux-core arc welding (FCAW) in low-alloy and mild-steel shipbuilding applications in wet environments was reported. On the basis of the survey, it was decided to pursue the development of underwater wet FCAW.

Given the success of using pulsed current for the SMAW repairs, the FCAW evaluations also incorporated pulsed current. A test matrix was developed to evaluate the following welding parameters: amperage, voltage, travel speed, polarity, lead angle, inductance, electrode extension, and filler metal. The researchers obtained approximately 12 filler materials from several manufacturers, including self-shielded (E308L-T3) and gas-shielded (E308L-T1) wires. The test welds were performed with a two-axis manipulator and machine torch at depths of 3 feet and 20 feet. More than 160 bead-on-plate welds (12 inches in length) and several fillet welds were completed and evaluated as part of the testing.

It was found that the range of suitable welding parameters is narrow for underwater wet FCAW. To obtain high-quality welds, close monitoring of the selected parameters was necessary. However, the most important variable was the consumable. For a number of the filler materials, the researchers could not establish a set of welding parameters that would provide a quality weld. After an extensive series of tests, they selected a specific wire that provided a sound weld with good mechanical properties and bead appearance.

During this development program, an EPRI member utility requested support in evaluating the feasibility of building up the welds on some of its jet pump riser brackets. The utility was concerned that resonant vibration could potentially crack the bracket welds. On the basis of a computer model, utility staff had determined that by adding weight to the brackets, they could change the resonant frequency, thus minimizing the vibrational problem.

In the EPRI test program, the selected 308L stainless steel filler metal provided welds that were free of porosity and slag. Tensile tests exceeded 93,000 psi, with failures occurring in the base metal. Bend tests and radiographs were acceptable under the ASME Section IX code requirements. Although the utility did not have to make a repair during the planned shutdown, it was ready to use this new technology if necessary.

Accomplishments and future plans

Weld qualification tests have been performed at a depth of 20 feet for both the SMAW and FCAW processes, using 308L filler materials. To date, the researchers have evaluated more than 30 SMAW and FCAW welding wires, producing underwater welds in all positions on Type 304 stainless steel base materials. This work has demonstrated the following:

- The SMAW and FCAW processes can each be used underwater to produce high-quality stainless steel welds with mechanical properties similar to those of conventional welds.
- For both SMAW and FCAW, the use of

Figure 2 A diver performs underwater wet welding (with the shielded metal arc process) at a depth of 20 feet. The use of pulsed current is an important factor in producing high-quality welds.

pulsed current improves penetration and bead appearance.

- Self-shielded FCAW can be performed remotely, allowing use in limited-access areas.
- Semiautomatic stainless steel FCAW is feasible underwater and can provide excellent weld quality.

Development is ongoing under the EPRI program. Additional work will develop new 308L FCAW filler materials to allow the welder operator more flexibility in welding input parameters. Further development is also planned for nickel-base welding alloys, which are common materials in reactor pressure vessel internals and attachments.

Air Quality Control

NOxPERT

by Angelos Kokkinos, Generation and Storage Division

Utilities with coal-fired boilers face technical and economic challenges in selecting combustion modifications to meet the revised Clean Air Act's requirements for controlling emissions of nitrogen oxides (NO_x). To help utilities select appropriate and effective approaches, EPRI has created NOxPERT™, an interactive computer program using the EPRIGEMS™ format. The program can estimate current NO_x emissions levels (in cases where actual levels are not known), select controls to meet emissions targets, and provide estimates on the cost of NO_x compliance. To achieve these objectives, NOxPERT requires information on boiler design and operation, coal type, and NO_x emissions limits.

ABSTRACT *The Clean Air Act Amendments of 1990 require existing utility power plants to control emissions of nitrogen oxides, primarily by using combustion modifications. The applicability, effectiveness, and cost of these control technologies depend very much on the design of the boiler and the characteristics of the coal burned. Choosing the most appropriate NO_x control technology can reduce the risks involved in the application of controls, as well as reduce a utility's capital outlay. EPRI has developed an easy-to-use, interactive computer model to help utilities make sound NO_x control decisions.*

The computer model

Effective compliance strategies are based on up-to-date, accurate, and objective information. To obtain this information for the algorithms built into the NOxPERT model, the project team reviewed the available literature and interviewed experts in NO_x control through combustion modification. (Noncombustion options like selective catalytic reduction and selective noncatalytic reduction were not considered.) On the basis of this information, the engineers and programmers created NOxPERT, which is capable of estimating current levels of NO_x emissions from coal-fired boilers and recommending a technology to meet user-specified reductions. The program provides technical advice about the selected technology and calculates the costs of implementation. It enables the user to examine the technical and economic implications of control legislation and of various NO_x reduction scenarios. NOxPERT is not intended, however, to be a substitute for emissions testing or detailed engineering studies and cost estimates of NO_x control implementation.

NOxPERT runs on IBM PCs, ATs, and PS/2s (and compatibles) that are equipped with EGA graphics and with the DOS operating system (Version 2.0 or higher). The program, based on the EPRIGEMS format, is user-friendly and requires minimal computer expertise. Pull-down menus and context-sensitive help screens explain the program operation and provide information on the function being performed.

Depending on the accuracy desired and on data availability, the information provided to NOxPERT can be quite specific. After the required boiler design and operational data are input, the design information can be saved in a single file; thus the user can test various operational scenarios without re-entering the design information.

Functions

NOxPERT performs three functions: an NO_x emissions estimate, a preliminary control analysis, and a detailed control analysis. The emissions estimate submodel calculates baseline, or uncontrolled, NO_x emissions from user-entered information on boiler design and operation. The boiler design data include physical dimensions, type of fuel-firing system (selected from a list), year of design permit and initial operation, number of burners, boiler manufacturer, maximum continuous rating, and heat rates. Operating information includes duty cycle (selected from a list), capacity factor, operating hours, and coal analysis data or coal rank and source. NO_x emissions are predicted by algorithms derived from national emissions data for the specific boiler design, corrected for operating and design conditions particular to the individual boiler.

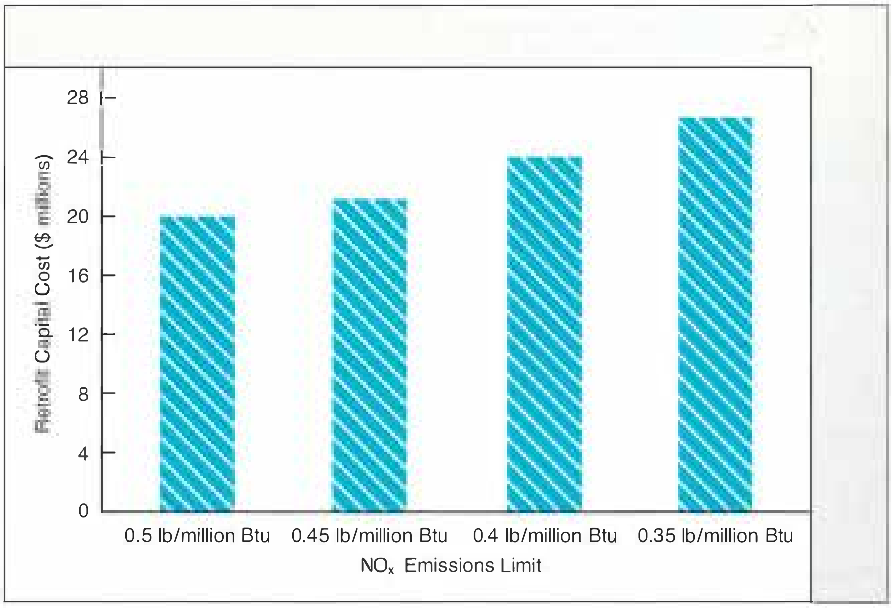
The preliminary NO_x control analysis requires the user to input additional information, such as the availability of reburn fuels. If full-load emissions data are available, they can be substituted for the predicted values. Then, using average boiler class data, NOxPERT evaluates the effects and costs of all relevant NO_x emissions control technologies based on combustion modification and selects the lowest-cost option that achieves the user-specified NO_x level. It also produces a report identifying the control costs, any potential technical impacts of applying the selected technology, and any uncertainties in the knowledge base for the technology.

The detailed NO_x control analysis overcomes some of the weaknesses of using average boiler class data. It allows the user to enter detailed design data (such as firebox dimensions, the number and location of burners, and information on digital controls, asbestos-bearing insulation, and gravimetric feeders) and detailed operating data, such as ash analysis results. NOxPERT uses these data to refine the emissions and cost estimates before control options are selected and reported. The selection is based on specific technical considerations particular to the user's boiler.

Control scenarios

When evaluating the effects and costs of NO_x reduction options (for either a preliminary or a detailed analysis), NOxPERT can consider one of three control scenarios: maximum reduction, boiler-by-boiler reduction, or "bubble" reduction (e.g., the targeting of a geographic area or a utility system).

Figure 1 This output from a detailed NOxPERT control analysis shows how the total capital cost of retrofitting five boilers with combustion modifications varies with the targeted NO_x emissions limit. Such results can help utilities develop effective NO_x compliance strategies.



In the first scenario, NOxPERT will select, for each boiler, the option that provides the maximum NO_x reduction without regard to cost. The program will also list all the applicable combustion NO_x control options for each boiler, along with their respective costs and emissions reductions (expressed as percentages and in tons per year).

For the boiler-by-boiler scenario, the user specifies a desired emissions level or percentage reduction; then, for each boiler, NOxPERT identifies the least expensive option (in terms of levelized cost) that meets this target. If the specified level cannot be met, the program will select the option offering the maximum reduction. Again, NOxPERT will report all the control options examined. When different boiler types require different NO_x reduction levels (e.g., for compliance with the new Clean Air Act amendments), the user can group boilers into operational files by category and do a separate analysis for each category.

In the bubble scenario, a desired area- or systemwide reduction or emissions level is specified; for the boilers in the group, NOxPERT selects the least expensive combination of options (in terms of levelized costs) that meets the target. Again, the user can treat several boilers as a subgroup (e.g., all tangentially fired boilers, all the boilers at a given power plant, all the boilers in a given county) and create a single operational data file for those units.

Once the program completes the designated analysis, it provides the user with a printable report that is displayed on the screen. The current NO_x emissions levels are summarized and compared with the required levels. For each boiler examined, a summary report recommends the most appropriate control technology and indicates why the other options evaluated were not selected. It also identifies any technical concerns or caveats associated with an option for the application under consideration. NOxPERT has a graphics subroutine that helps users compare the results of different analyses.

Earlier this year, several members tested the beta version of NOxPERT. EPRI is incorporating their recommended changes into the program and expects to release it as a production code this winter through the Electric Power Software Center. For further information, contact Angelos Kokkinos, (415) 855-2494.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Advanced Lighting System Development, Evaluation, Demonstration, and Market Introduction (RP2285-27)	$65,000 18 months	Lighting Research Institute/*K. Johnson*
Snohomish–Bonneville Power Administration Commercial Case Study (RP2671-6)	$132,300 11 months	National Analysts/ *T. Henneberger*
HydroTech 2000 Heat Pump Testing (RP2892-20)	$246,900 15 months	Geomet Technologies/ *J. Kesselring*
Thermal Performance of Unsaturated Soils and Backfill (RP3024-3)	$188,300 26 months	South Dakota State University/*P. Joyner*
Variable-Speed Ground-Source Heat Pump (RP3024-4)	$69,800 15 months	University of Alabama/ *P. Joyner*
Study of a Regional Intermodal Transportation Center and High-Speed Rail Link (RP3025-4)	$50,000 14 months	Greater Rockford Airport Authority/*L. O'Connell*
Electrical Systems		
Advanced Power Transformer, Phase 3 (RP3210-2)	$1,584,800 10 months	ABB Power T&D Co./ *S. Lindgren*
Microscopic Probes of High-Temperature Superconductivity (RP4000-39)	$100,000 39 months	Virginia Commonwealth University/*M. Rabinowitz*
EHV Cable Research and Test Laboratory (RP7899-32)	$1,967,500 60 months	Westinghouse Electric Corp./*F. Garcia*
Environment		
Groundwater Database System Development (RP2485-23)	$118,800 9 months	Southern Company Services/*I. Murarka*
Land Application Uses for FGD By-products (RP2796-2)	$400,000 50 months	Dravo Lime Co./*I. Murarka*
Evaluation of Alternative Land Surface Parameterization (RP2938-3)	$104,900 11 months	University of Washington/ *D. McIntosh*
Childhood Leukemia and Exposure to Power Frequency EMF: Epidemiological Studies (RP2964-12)	$381,000 59 months	Canadian Electrical Association/*R. Black*
Childhood Cancer: Role of EMF as a Promoter (RP2964-13)	$388,900 11 months	ENSR Health Sciences/ *L. Kheifets*
Exploratory and Applied Research		
Effects of Refractory Metals on Scaling of Fe-Ni-Cr Alloys in Mixed Oxidants (RP2426-35)	$295,600 38 months	Lockheed Missiles & Space Co./*W. Bakker*
Evaluation of Diffusion Coating for Application in Utility Boilers (RP2426-37)	$102,900 71 months	Babcock & Wilcox Co./ *B. Dooley*
Material Fracture Properties by Small-Punch Testing (RP2426-38)	$220,900 21 months	Failure Analysis Associates/ *R. Viswanathan*
Adhesion and Mechanical Properties of Chemical Vapor Deposition Diamond Films: Fundamental Studies (RP2426-46)	$140,200 12 months	Stanford University/ *J. Stringer*
Characterization of Ceria-Zirconia and Bismuth Oxide–Zirconia Low-Temperature Composite Solid (RP8002-30)	$297,000 36 months	University of Utah/ *R. Goldstein*
R&D Opportunities in Electrosynthesis and Electrochemical Manufacturing (RP8002-31)	$63,900 7 months	Dextra Associates/ *A. Amarnath*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Generation and Storage		
Development of Low-NO_x, Low-Particulate Burner Hardware (RP2869-13)	$150,000 23 months	ESEERCO/*D. Eskinazi*
CAES Demonstration Plant: Computer Programming and Data Acquisition (RP2894-10)	$194,600 22 months	Energy Storage and Power Consultants/ *R. Pollak*
Evaluation of Gas Reburning and Low-NO_x Burners in a Wall-Fired Boiler (RP2916-23)	$200,000 35 months	Energy and Environmental Research Corp./ *A. Kokkinos*
Turbomachinery Expert System (RP2923-4)	$488,200 36 months	General Electric Co./ *J. Scheibel*
Combustion Emissions Model and Software Development (RP2947-5)	$71,700 1 month	Carnot/*W. Rovesti*
Atmospheric Fluidized-Bed Combustion Site Support (RP3162-2)	$106,300 9 months	Hamilton Maurer International/*T. Boyd*
Development of Index Systems for Coal Combustion By-products (RP3176-2)	$222,800 49 months	Southern Company Services/*D. Golden*
Characterization of Toxic Emissions From Western-Coal-Fired Utility Boilers (RP3177-4)	$110,000 23 months	Sierra Pacific Power Co./ *W. Chow*
Demonstration of a Molten Carbonate Fuel Cell on Coal-Derived Gas (RP3195-1)	$503,700 8 months	Destec Energy/*D. Rastler*
Computer-Aided Inspection of Combustion Turbines (RP3250-1)	$390,500 18 months	Southwest Research Institute/*G. Quentin*
SA•VANT-Based Interactive Video Pilot Training Program on Combustion Fundamentals (RP3250-2)	$173,500 10 months	Southwest Research Institute/*G. Quentin*
Intelligent Training for Gas Turbine Startup Diagnosis (RP3250-5)	$162,700 9 months	Galaxy Scientific Corp./ *G. Quentin*
Integrated Energy Systems		
Integrated Framework for Research Planning and Policy Analysis of Global Climate Change (RP3236-2)	$250,000 11 months	Carnegie-Mellon University/*V. Niemeyer*
Compliance Planning and Emissions Trading: Analysis of Critical Issues (RP3273-1)	$300,000 9 months	Andrew J. Van Horn/ *J. Platt*
Nuclear Power		
Advanced LWR Program Requirements Document (RP3260-6)	$150,000 12 months	Stone & Webster Engineering Corp./ *E. Whitaker*
Advanced LWR Phase 3 Passive Plant Requirements (RP3260-14)	$495,300 14 months	Grove Engineering/ *E. Whitaker*
PWR Control Rod Worth Calibration (RP3262-1)	$108,400 16 months	Utility Resources Association/*R. Breen*
Evaluation of BWR Mixed Cores (RP3293-1)	$150,000 21 months	S. Levy, Inc./*L. Agee*
Review of Qualification Program for Chemically Decontaminating a Commercial PWR (RP3307-1)	$58,800 4 months	NWT Corp./*C. Wood*
Full-System Decontamination Application Assistance (RP3307-2)	$75,000 11 months	J. A. Jones Applied Research Co/*C. Wood*
Hydrogen Water Chemistry Effect on Radiation Buildup (RP3313-1)	$96,500 10 months	General Electric Co./ *C. Wood*

New Technical Reports

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

CUSTOMER SYSTEMS

Environmental Externalities: An Overview of Theory and Practice
CU/EN-7294 Final Report (RP2982-6); $200
Contractor: Temple, Barker & Sloane, Inc.
EPRI Project Managers: P. Hanser, V. Niemeyer

Modeled and Measured Infiltration: A Detailed Case Study of Four Electrically Heated Homes
CU-7327 Final Report (RP2034-40); $200
Contractors: Ecotope, Inc.; Lawrence Berkeley Laboratory
EPRI Project Manager: J. Kesselring

Supermarket Refrigeration Assessment for the Commonwealth Electric Company
CU-7379 Final Report (RP2569-9); $200
Contractor: Foster-Miller, Inc.
EPRI Project Manager: M. Khattar

Residential Duct Design: A Practical Handbook
CU-7391 Special Report (RP2892-12); $50
Contractors: Ball State University; PSI Energy
EPRI Project Manager: A. Lannus

Residential Energy Usage Comparison: Findings
CU-7392 Final Report (RP2863-3); $200
Contractor: Quantum Consulting, Inc.
EPRI Project Managers: P Cleary, S. Braithwait, P. Meagher

The Revised National Electrical Code for New Restaurants
CU-7428 Final Report (RP2890-17); $200
Contractors: Hart, McMurphy & Parks, Inc.; Charles N. Claar
EPRI Project Manager: K. Johnson

Proceedings: Electric Thermal Storage/Thermal Energy Storage 1990
CU-7430 Proceedings (RP2731-11); $200
Contractor: Policy Research Associates, Inc.
EPRI Project Manager: J. Kesselring

Analysis of Annual Thermal and Moisture Performance of Radiant Barrier Systems
CU-7472 Final Report (RP2034-30); $200
Contractor: Oak Ridge National Laboratory
EPRI Project Manager: J. Kesselring

ELECTRICAL SYSTEMS

Characterization of Cable Insulation Materials, Vol. 2: Dynamic Mechanical Spectroscopy Studies
EL-7076 Final Report (RP7897-1); $200
Contractor: Battelle, Columbus Division
EPRI Project Manager: B. Bernstein

Advanced Thyristor Valve Project
EL-7169 Final Report (RP1291-3, -5); $200
Contractor: General Electric Co.
EPRI Project Manager: B. Damsky

Accessories for Specially Bonded Extruded-Dielectric Transmission Cable Systems, Vols. 1 and 2
EL-7259 Final Report (RP7893-1); $200 each volume
Contractors: McGraw-Edison Power Systems; Pirelli Cable Corp.
EPRI Project Manager: F. Garcia

Underground Transmission Computer Program: Debugging and Field Testing of the ICO Pipe Coupler, Vols. 1 and 2
EL-7299 Final Report (RP7898-14); $200 each volume
Contractor: Foster-Miller, Inc.
EPRI Project Manager: T. Rodenbaugh

Space Charge Measurement in DC Cable Materials
EL-7301 Final Report (RP7897-11); $200
Contractor: National Institute of Standards and Technology
EPRI Project Manager: B. Bernstein

Terminations for Extruded-Dielectric Cables Rated 69 kV and 138 kV
EL-7331 Final Report (RP7901-1); $200
Contractor: Underground Systems, Inc.
EPRI Project Manager: F Garcia

Single-Conductor Transmission Cable Magnetic Fields
EL-7340 Final Report (RP7898-29); $500
Contractor: Power Technologies, Inc.
EPRI Project Manager: J. Shimshock

Dynamic Rating and Underground Monitoring System (DRUMS)
EL-7341 Final Report (RP7898-3); $200
Contractor: Underground Systems, Inc.
EPRI Project Manager: F. Garcia

Simultaneous Transfer Capability: Direction for Software Development
EL-7351 Final Report (RP3140-1); $200
Contractor: Union Electric Co.
EPRI Project Manager: M. Lauby

Algorithm for Detecting Energy Diversion
EL-7356 Final Report (RP2739-1); $200
Contractor: Boeing Computer Services
EPRI Project Manager: H. Ng

Evaluation of Transient Energy Function Method Software for Dynamic Security Analysis
EL-7357 Final Report (RP4000-18); $200
Contractor: MACRO Corp.
EPRI Project Manager: M. Lauby

Network Analysis of Ground Currents in a Residential Distribution System
EL-7369 Interim Report (RP3335-2); $295
Contractor: General Electric Co.
EPRI Project Manager: G. Rauch

Cross-Linked Polyethylene Cable Insulation: Electrically Stimulated Acoustic Wave Measurements
EL-7402 Final Report (RP7898-20); $200
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: B. Bernstein

An Investigation of the Interfacial Bond Strength of Polymeric Laminates
EL-7404 Final Report (RP7880-8); $200
Contractor: Johns Hopkins University
EPRI Project Manager: B. Bernstein

Phase-Modulated Fiber-Optic Current Transformer/Voltage Transformer
EL-7421 Final Report (RP2734-3); $200
Contractor: Optical Technologies, Inc.
EPRI Project Manager: J. Porter

EXPLORATORY AND APPLIED RESEARCH

Algal Refossilization of Atmospheric Carbon Dioxide
EAR-7401 Interim Report (RP8011-5); $200
Contractor: Neushul Mariculture, Inc.
EPRI Project Manager: J. Berning

Biological Solubilization of Low-Rank Coal
EAR-7431 Final Report (RP8003-6); $200
Contractor: University of Hartford
EPRI Project Manager: S. Yunker

Molecular Structure of Coal and Coal Macerals
EAR/GS-7437 Final Report (RP8003-21); $200
Contractor: Southern Illinois University at Carbondale
EPRI Project Manager: S. Yunker

GENERATION AND STORAGE

Derivation of Induction Motor Models From Standstill Frequency Response Tests
GS-6250 Final Report (RP2328-4); $200
Contractor: Power Technologies, Inc.
EPRI Project Manager: J. Edmonds

Characterizing Fuels for Utility-Scale Atmospheric Fluidized-Bed Combustors
GS-7208 Final Report (RP718-2); $200
Contractors: Babcock & Wilcox Co.; Oak Ridge National Laboratory; Combustion Systems, Inc.
EPRI Project Manager: J. Stallings

Experiences and Lessons Learned With Residential Photovoltaic Systems
GS-7227 Final Report (RP1607-15); $200
Contractor: Ascension Technology, Inc.
EPRI Project Manager: F Goodman

Experimental Verification of Scaling Relationships for Circulating Fluidized Beds
GS-7228 Interim Report (RP979-21); $200
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: J. Stallings

Gas Turbine Selective Catalytic Reduction Procurement Guidelines
GS-7254 Final Report (RP2936-1); $2500
Contractor: Radian Corp.
EPRI Project Manager: H. Schreiber

Design, Performance, Operation, and Maintenance of Fabric Filters in the Utility Industry
GS-7287 Final Report (RP1129-8); $200
Contractor: Southern Research Institute
EPRI Project Manager: R. Chang

Effluent Variability in the Iron Hydroxide Adsorption/Coprecipitation Process
GS-7308 Final Report (RP910-3); $200
Contractor: Brown and Caldwell Consultants
EPRI Project Manager: M. McLearn

Decision Support Methods for the Electric Power Industry, Vols. 1 and 2
GS-7344 Proceedings (RP2923-7); $200 for set
Contractor: Applied Decision Analysis
EPRI Project Managers: J. Valverde, M. Divakaruni

Proceedings: Condenser Technology Conference
GS-7349 Proceedings (RP1689-23); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager J. Tsou

Generator Unbalanced Load Capability
GS-7393 Final Report (RP2591-1); $200
Contractor: Nippes Professional Associates, Inc.
EPRI Project Managers: J. Edmonds, J. Stein

Shell Coal Gasification Plant (SCGP-1) Environmental Performance Results
GS-7397 Interim Report (RP2695-1); $200
Contractor: Shell Development Co.
EPRI Project Manager: N. Stewart

Suction Effects on Feedpump Performance
GS-7398 Final Report (RP1884-10); $200
Contractor: Sulzer Brothers, Ltd.
EPRI Project Managers: S. Pace, T. McCloskey

Rotor Dynamic and Thermal Deformation Tests of High-Speed Boiler Feedpumps
GS-7405 Final Report (RP1884-10); $200
Contractor: Sulzer Brothers Ltd.
EPRI Project Managers: S. Pace, T. McCloskey

Vibration Sensor Mounting Guideline
GS-7406 Special Report (RP1864-4); $200
Contractor: Computational Systems, Inc.
EPRI Project Manager: J. Scheibel

Monitoring and Diagnostic Center: An Overview of Operating Activities
GS-7407 Interim Report (RP2817-1); $200
Contractor: Philadelphia Electric Co.
EPRI Project Managers: J. Scheibel, R. Colsher

Vibration Signature Analysis Monitoring System
GS-7408 Final Report (RP1864-1); $200
Contractor: Mechanical Technology, Inc.
EPRI Project Manager: J. Scheibel

Centrifugal Fan Monitoring Guidelines
GS-7409 Final Report (RP1864-4); $200
Contractor: Computational Systems, Inc.
EPRI Project Manager: J. Scheibel

Rotor Bar Thermal Monitoring in Large Asynchronous Motors
GS-7415 Final Report (RP2591-10); $200
Contractor: Spectra Technology, Inc.
EPRI Project Managers: J. Edmonds, J. Stein

Dry Cooling: Perspectives on Future Needs
GS-7446 Final Report (RP422-13); $200
Contractor: Yankee Scientific, Inc.
EPRI Project Manager: J. Bartz

INTEGRATED ENERGY SYSTEMS

UNISAM User's Manual
IE-7296 Final Report (RP3199-5); $200
Contractor: ARINC Research Corp.
EPRI Project Manager: J. Weiss

NUCLEAR POWER

Lubrication Guide (Revision 1)
NP-4916 Final Report (RP2814-21); $2800
Contractor: Robert O. Bolt
EPRI Project Manager: V. Varma

Generic Seismic Ruggedness of Power Plant Equipment (Revision 1)
NP-5223-M Final Report (RP1707-15, RP2925-2); $200
Contractor: ANCO Engineers, Inc.
EPRI Project Manager: R. Kassawara

MIST Final Report, Vols. 1 and 11
NP-6480 Final Report (RP2399-1); $200 each volume
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: J. Sursock

Proceedings: Eleventh Annual EPRI Nondestructive Evaluation Information Meeting
NP-7047-M Proceedings (RP1570-14); $200
NP-7047-SD Proceedings; $200
EPRI Project Managers: S. Liu, M. Avioli

Seismic Ruggedness of Relays
NP-7147-M Final Report (RP1707-15); $200
Contractor: ANCO Engineers, Inc.
EPRI Project Manager: R. Kassawara

The Effects of Transuranic Separation on Waste Disposal
NP-7263 Final Report (RP3030); $32.50
Contractor: Rogers and Associates Engineering Corp.
EPRI Project Managers: E. Rodwell, R. Williams

International Programs Related to the Transmutation of Transuranics
NP-7265 Final Report (RP3030); $25
EPRI Project Manager: E. Rodwell

Large Steam Turbine Repair: A Survey
NP-7385 Final Report (RP1929-15); $200
Contractor: EPRI Nondestructive Evaluation Center
EPRI Project Manager: W. Childs

Aluminum Honeycomb Impact Limiter Study
NP-7389 Final Report (RP2813-18); $200
Contractors: Nuclear Assurance Corp.; Applied Science and Technology
EPRI Project Manager: R. Williams

Guide for Monitoring Equipment Environments During Nuclear Plant Operation
NP-7399 Final Report (RP2927-6); $500
Contractor: Grove Engineering, Inc.
EPRI Project Manager: G. Sliter

Fuel-Assembly Behavior Under Dynamic Impact Loads Due to Dry-Storage Cask Mishandling
NP-7419 Final Report (RP2813-9, -28); $200
Contractors: ABB Combustion Engineering, Inc., Anatech Research Corp.
EPRI Project Manager: O. Ozer

Fractographic Analysis of a Crack in a Zion Steam Generator
NP-7420 Interim Report (RP3154-2); $200
Contractor: SRI International
EPRI Project Manager: J. Nelson

Risk-Based Technical Specifications Program
NP-7436 Interim Report (RP3184-1); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Sursock

Application of Electromagnetic Acoustic Transducers to Coarse-Grained Material
NP-7438 Final Report (RP2687-5); $200
Contractor: Magnasonics. Inc.
EPRI Project Manager: M. Behravesh

CALENDAR

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

JANUARY 1992

14–15
Plant Process Computer Replacement
Columbia, South Carolina
Contact: Susan Bisetti, (415) 855-7919

14–16
Rolling Element Bearings: Life Improvement Course
Eddystone, Pennsylvania
Contact: Murthy Divakaruni, (415) 855-2409

16
NMAC Workshop: Computer-Oriented Maintenance Application System
Chicago, Illinois
Contact: Jim Christie, (704) 547-6053

21
NMAC Workshop: Computer-Oriented Maintenance Application System
Miami, Florida
Contact: Jim Christie, (704) 547-6053

21–23
Motor Monitoring and Diagnostics Course
Eddystone, Pennsylvania
Contact: John Scheibel, (415) 855-2850

23–24
Workshop: Static Electrification in Power Transformers
San Jose, California
Contact: Stan Lindgren, (415) 855-2308

23–24
Workshop: GE Low-Voltage Breaker Maintenance
Newport News, Virginia
Contact: Jim Christie, (704) 547-6053

29–31
Conference: Steam and Combustion Turbine Blading
Orlando, Florida
Contact: Lori Adams, (415) 855-8763

FEBRUARY

4–7
Advanced Machinery Vibration Diagnostics
Eddystone, Pennsylvania
Contact: Murthy Divakaruni, (415) 855-2409

5–7
Advanced Digital Computers, Controls, and Automation Technologies
San Diego, California
Contact: Pam Turner, (415) 855-2010

11–13
Industrial Safety Innovations in Nuclear Power Plant O&M
Charlotte, North Carolina
Contact: John O'Brien, (415) 855-2214

24–25
Seminar: Nuclear Power Plant Performance Improvement
Miami, Florida
Contact: Bob Edwards, (415) 855-8974

MARCH

3–5
Seminar: Substation Voltage Upgrading
Denver, Colorado
Contact: Joe Porter, (202) 872-9222

16–17
Investment and Research Planning Forum
Atlanta, Georgia
Contact: Susan Bisetti, (415) 855-7919

17–18
Storage—1993 and Beyond
Orlando, Florida
Contact: Linda Nelson, (415) 855-2127

APRIL

7–9
Workshop: Achieving Accurate Coal Weighing and Sampling Systems
St. Louis, Missouri
Contact: David O'Connor, (415) 855-8970

8–9
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

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

MAY

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

26–29
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
Controls and Instrumentation Conference
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

JULY

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

6–9
2d International Conference on Compressed-Air Energy Storage
San Francisco, California
Contact: Lori Adams, (415) 855-8763

7–9
Workshop: NO_x Control
Boston, Massachusetts
Contact: Pam Turner, (415) 855-2010

AUGUST

24–26
Optical Sensing
Philadelphia, Pennsylvania
Contact: Linda Nelson, (415) 855-2127

25–27
Effects of Coal Quality on Power Plants
San Diego, California
Contact: Susan Bisetti, (415) 855-7919

SEPTEMBER

13–16
International Conference: Avian Interactions With Utility Structures
Miami, Florida
Contact: Pam Turner, (415) 855-2010

Authors and Articles


Porcella


Huckabee


Goldstein


Birk


Schainker


O'Brien

Mercury in the Environment (page 4) was written by science writer John Douglas with information provided by three members of EPRI's Environment Division.

Don Porcella, a project manager for studies of aquatic ecosystems, joined EPRI in 1984 after six years with Tetra Tech, a Honeywell R&D and consulting subsidiary. Previously he was a professor of civil and environmental engineering at Utah State University and the associate director of the Utah Water Research Laboratory. Porcella holds BA and MA degrees in zoology and a PhD in environmental health sciences, all from the University of California at Berkeley.

John Huckabee manages EPRI's Ecological Studies Program. He has also worked as a project manager on studies dealing with toxic substances, terrestrial and aquatic resources, and atmospheric deposition since joining the Institute in 1979. Earlier he spent eight years in the Environmental Sciences Division at Oak Ridge National Laboratory. Huckabee earned a BS in biology at Sul Ross State University (Texas) and MS and PhD degrees in zoology and physiology at the University of Wyoming.

Robert Goldstein is the program manager for EPRI's work in ecosystem analysis. He has been with the Institute since 1985, largely focusing on atmospheric deposition effects, forest stress, and genetic ecology. Goldstein previously worked for more than five years as a systems ecologist at Oak Ridge National Laboratory. He has a BS in engineering and MS and PhD degrees in nuclear science and engineering from Columbia University. ■

Alabama Cooperative Generates Power From Air (page 12) was written by Leslie Lamarre, *Journal* feature writer, with assistance from two members of the Generation and Storage Division.

Jim Birk is director of the Storage and Renewables Department, a position he has held for more than three years. He previously directed R&D programs in advanced energy conversion and storage. He came to EPRI in 1973 as a project manager for battery storage development and before that was a senior scientist with Rockwell International for seven years. Birk has a BS in chemistry from Iowa State University and a PhD in analytical chemistry from Purdue University.

Robert Schainker is manager of the Energy Storage Program, a position he has held since 1985. Schainker joined EPRI in 1978 as a project manager in the former Advanced Power Systems Division. His previous experience includes nine years with Systems Control, Inc., of Palo Alto. Schainker has a BS in mechanical engineering, an MS in systems engineering, and a PhD in applied mathematics from Washington University in St. Louis. ■

Lights! Camera! And . . . Maintenance! (page 20) was written by Taylor Moore, *Journal* senior feature writer, with assistance from **John O'Brien** of EPRI's Nuclear Power Division.

O'Brien, manager of the Nuclear Plant Operations and Maintenance Program, has been with EPRI since 1979, specializing in human factors engineering. He previously worked for five years in man-machine studies at the Westinghouse R&D Center and before that was a research analyst at the Center for Occupational Education at North Carolina State University. O'Brien received BA, MA, and PhD degrees in industrial and engineering psychology from North Carolina State. ■

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

ADDRESS CORRECTION REQUESTED

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

EPRI JOURNAL

December 1991