Measuring Emissions in Micrograms

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ELECTRIC POWER RESEARCH INSTITUTE

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

Brent Barker, Manager
Corporate Information

Richard G. Claeys, Vice President
Corporate Communications

Graphics Consultant: Frank A. Rodriquez

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

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Cover: The extremely low concentrations of many trace chemicals emitted from power plants are challenging the capabilities of existing measurement technology.

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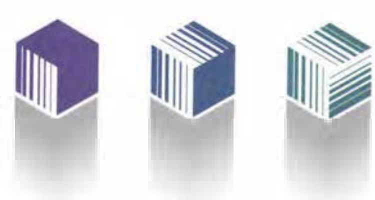

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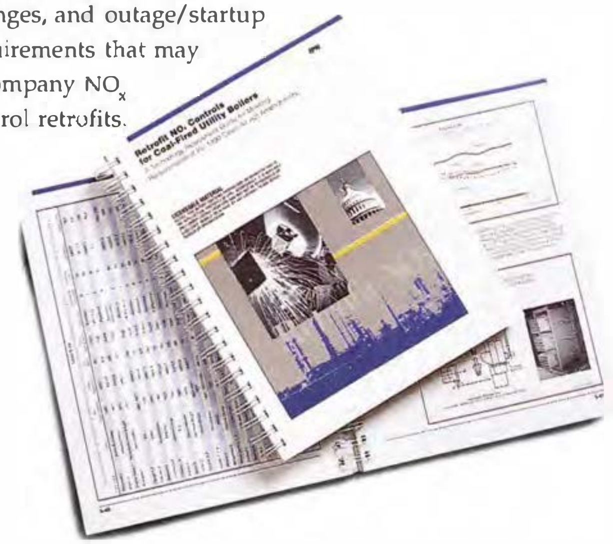
For more information, contact Tom Rodenbaugh, (415) 855-2306, or Tom Kendrew, (415) 855-2317. To order or lease, call Gerard Pittard at Guided Boring Systems, Inc., (713) 683-8961.

Guide to NO_x Control

Utility managers and engineers responsible for controlling emissions of nitrogen oxides (NO_x) eagerly welcomed the recent publication of *Retrofit NO_x Controls for Coal-Fired Utility Boilers* (TR-102906). Specifically developed to help utilities best meet the NO_x reduction provisions of the Clean Air Act Amendments of 1990, this 200-page resource provides comprehensive information on commercially available NO_x controls for pulverized-coal boilers. The guide offers details on costs and other critical issues to consider in assessing and selecting NO_x control equipment—issues such as equipment modifications, operational changes, and outage/startup requirements that may accompany NO_x control retrofits.



For more information, contact David Eskinazi, (202) 293-7515. To order, call the EPRI Distribution Center, (510) 934-4212.

Service Water System Videos

With the help of this two-volume video set, utilities can initiate preventive maintenance programs for service water systems and reduce the likelihood of costly system failures. The videos (VT-100388) are designed to instruct power plant engineers in performing visual inspections of service water systems. The introductory tape presents a comprehensive overview of various service water system degradation mechanisms, including corrosion, lining failure, mechanical fatigue, and fouling. The second tape documents instances of service water system degradation that have occurred in power plants throughout the United States. Although the videos are geared toward system engineers at nuclear power plants, system engineers at nonnuclear plants will also find them useful.

For more information, contact Bob Edwards, (415) 855-8974. To order, call the EPRI Distribution Center, (510) 934-4212.

Reference on Aging Terminology

Error-induced stressor. Age conditioning. Synergistic effects. Degraded failure. What exactly do these terms mean? As nuclear power plants grow older, it's becoming increasingly important for the industry's experts to speak the same language when it comes to communicating about life- and aging-management issues. That's why EPRI coordinated the development of *Nuclear Power Plant Common Aging Terminology* (TR-100844), a reference book that defines 85 terms (and 27 synonyms) used to communicate about the aging of nuclear plant systems, structures, and components. Not only can this resource help improve understanding of aging phenomena, but it also facilitates the reporting of experiences with component reliability and failure. Several electric utilities, the Nuclear Management and Resources Council, the Nuclear Regulatory Commission, and national laboratories collaborated with EPRI on the development of these terms and definitions. For convenience, a pocket-sized version (BR-101747) is also available.

For more information, contact George Sliter, (415) 855-8699. To order, call the EPRI Distribution Center, (510) 934-4212.

Field Trapping Makes Magnetic Replicas

The discovery of high-temperature superconductors (HTSCs) has led to considerable excitement about building large superconducting magnets for use in the electric utility industry. Potential applications range from motors and generators to circuit breakers and energy storage systems. Building large electromagnets with coils of HTSC wire is difficult, however, because of the brittleness and low current-carrying capacity of HTSCs. An alternative approach that is gaining increased attention involves creating the superconducting equivalent of permanent magnets.

When a piece of HTSC material is placed in a magnetic field, some of the field is trapped by the material and persists even when the external field is shut off. The trapped field is a faithful replica of the original, regardless of the shape of the HTSC material. In contrast, the field of an ordinary permanent magnet is determined primarily by the magnet's shape. A potential advantage of using superconducting magnetic replicas, therefore, is that the field configuration can be optimized for a particular application without costly machining or fabrication of an electromagnet.

Trapped fields allow two small superconductors to float stably beneath a conventional magnet.

For a long time such field trapping was thought to be impossible because of the so-called Meissner effect—the tendency of superconducting materials to expel magnetic fields. The familiar pictures of a small magnet suspended above a superconductor show the Meissner effect in action. Imperfections in the crystal lattice of superconducting materials, however, result in pinning forces that can trap magnetic fields and create magnetic replicas. This phenomenon, called the very incomplete Meissner effect (or sometimes the anti-Meissner effect), is demonstrated by the ability of "magnetically charged" superconductors to float stably beneath a magnet, held by fields they have trapped.

Recently, EPRI-sponsored research at the University of Houston resulted in new records for magnetic replicas—a 39,600-gauss stable field and a 70,000-gauss temporary field at 65 K. The trapping of the stable field was enhanced by irradiating the HTSC material to create the lattice imperfections that would facilitate increased magnetic flux pinning. Related research continues.

"Flux trapping may provide a way around the mechanical and electrical difficulties of HTSCs," says EPRI senior physicist Mario Rabinowitz, who first reported evidence of field trapping in 1973 (culminating in the trapping of 22,400 gauss) and holds patents related to potential applications. "One of the most important uses of magnetic replicas could be in energy storage systems, for example. Such systems would use a normal coil to create a large magnetic field in HTSC material in bulk—perhaps even granular—form, thus eliminating the need to fabricate HTSC wire."

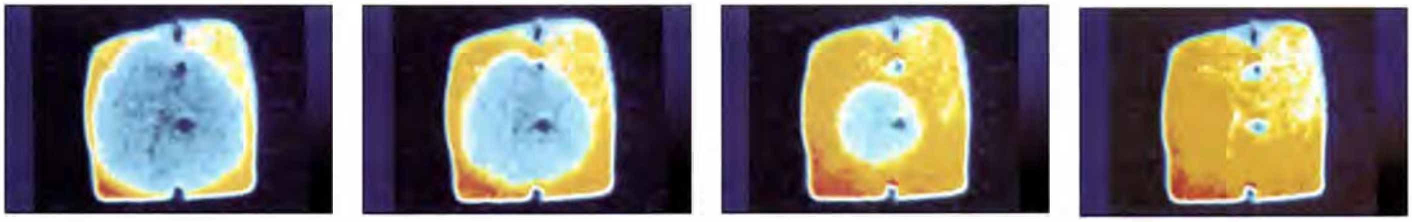
■ *For more information, contact Mario Rabinowitz, (415) 855-2280.*

Using MRI to Optimize Food Freezing

Although preserving foods by freezing is a long-established practice, the process itself has not been well optimized because of difficulties in monitoring heat removal. To ensure product quality, foods are routinely "overfrozen," which results in removing 20–40% more heat energy (enthalpy) than required. Now, magnetic resonance imaging (MRI) offers a way to increase the efficiency of the freezing process through on-line monitoring of ice formation within actual products.

MRI produces computer-generated images of the hydrogen density inside objects and was initially developed for medical applications, such as identifying tumors. It can also be used to track the movement of the ice-water interface in foods as they freeze. With EPRI funding, researchers at the University of California at Davis have been exploring this option, using standard MRI equipment

MRI images track the progressive freezing of a steak by delineating the ice-water interface.



and specially modified freezers that are compatible with the imaging configuration.

The researchers monitored freezing in a wide variety of foods, ranging from peas and carrots to beef, chicken, and even cantaloupe. The data were then confirmed by comparison with results obtained through standard calorimetry and were incorporated into product-specific mathematical models. Such models can be used to optimize freezing times and conditions and thus reduce energy loss.

A preliminary economic analysis conducted by the UC Davis team suggests that MRI technology adapted for use by the food industry would find a substantial market. Energy savings alone could be expected to prompt the adoption of MRI monitoring by food-processing plants, and the goal of quality improvement in frozen products may provide further incentives. Food freezing now consumes about 450 million kWh of electric energy, and optimization of the process could lead to estimated energy savings of 5–20%.

"Our work at Davis provided proof ofconcept confirmation for MRI monitoring and led to the development of design criteria for commercial MRI food-processing sensors," says Ammi Amarnath, manager of the project. "EPRI is now exploring prototype development with potential manufacturers."

■ *For more information, contact Ammi Amarnath, (415) 855-2548.*

Ultralow-NO_x Burner Based on Swirling Air

Reducing the formation of nitrogen oxides (NO_x) during combustion in utility boilers depends on carefully controlling the temperature and fuel-air mixture in various parts of the flame. Ideally, combustion takes place in two stages. During the first stage, the oxygen supply is limited so that the fuel is pyrolyzed and releases nitrogen in its innocuous molecular form (N_2). In a second, oxygen-rich stage, combustion of the remaining fuel is completed.

But creating such staged combustion is tricky. One approach is to inject air through multiple ports and thus form distinct flame zones inside the combustion chamber. Multiple ports are expensive, however, and physically separated flame zones can aggravate corrosion on the chamber surface. A second approach is to create a single flame with multiple stages by using a low-NO_x burner with complex fuel-air mixing patterns. So far, though, such burners have been able to cut NO_x emissions by only about half—not enough to meet the new standards set for the latter part of this decade.

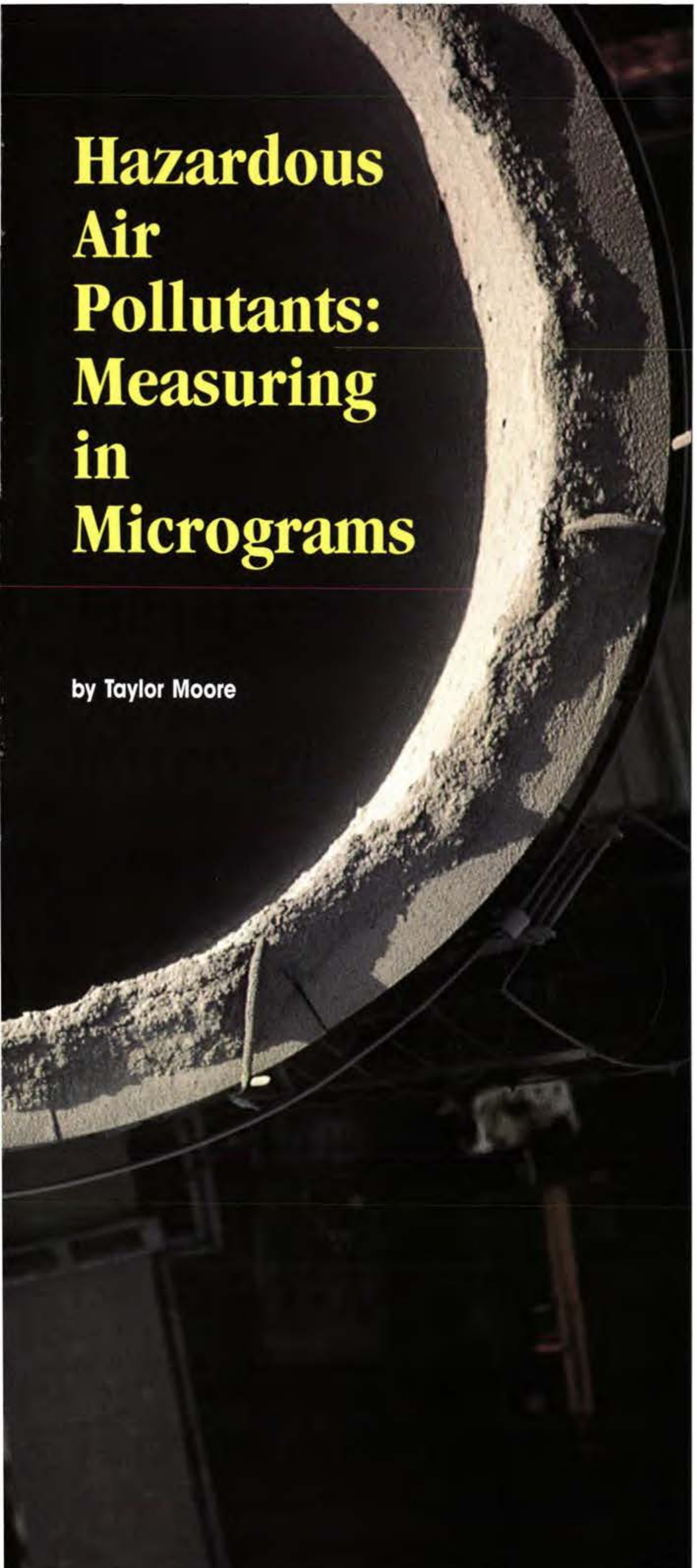
Now, researchers at the Massachusetts Institute of Technology have discovered a novel way to improve low-NO_x burners. In laboratory tests, the MIT scientists have been able to reduce NO_x emissions to about 15% of uncontrolled levels. This success is based on elongating the flame by swirling air around it. A longer flame promotes fuel pyrolysis and delays full combustion.

The researchers are using a device called a radially stratified flame core (RSFC) burner. It consists of a central nozzle for injecting fuel, surrounded by three concentric annular nozzles that introduce separate layers of swirling air. The rotation of the air creates a centrifugal force that damps flame turbulence, sustains stable layers of fuel and air, elongates the flame, and delays mixing. To further increase the effectiveness of this system, steam is mixed with the fuel before injection, and flue gas is mixed with air in two of the outer nozzles.

Because of successful tests at MIT of a 1-MWth RSFC burner fueled by natural gas, a consortium of funding organizations is sponsoring the development of two prototypes: a 23-MWth burner for utility demonstration and a burner for use with oil as well as gas. Commercialization of the multifuel burner is expected in late 1995.

■ *For more information, contact John Maulbetsch, (415) 855-2438.*

THE STORY IN BRIEF In response to recent concerns about trace emissions of potentially hazardous chemicals, EPRI has initiated several cooperative research projects to improve understanding of stack emissions from electric utility fossil fuel power plants. These projects are beginning to provide answers to some of the fundamental questions now being faced by decision makers weighing the effects of these emissions: What chemicals are emitted and in what quantities? What are the potential risks to public health and the environment from utility releases of such substances? How effective are existing environmental control systems in removing the chemicals of concern? What are the costs of further control? The initial step in EPRI's efforts to deal with these questions has been to characterize utility chemical emissions with unprecedented accuracy.



Hazardous Air Pollutants: Measuring in Micrograms

by Taylor Moore

Most utilities operating fossil power plants are in the midst of implementing plans to comply with sections of the Clean Air Act Amendments (CAAA) of 1990—the sections commonly referred to as the acid rain provisions—mandating reductions in emissions of sulfur and nitrogen oxides over the next several years. But another section (Title III) of the law mandates that the Environmental Protection Agency (EPA) require U.S. industrial facilities—with the exception of electric utility steam generating plants—that emit more than 10 tons per year of any one, or 25 tons per year of any combination, of 189 designated "hazardous air pollutants" to apply maximum achievable control technology (MACT); additional controls are required if residual risk remains. This list of hazardous air pollutants, popularly called air toxics, includes heavy metals, organic compounds, and some inorganic substances in gaseous, particulate, and aerosol forms.

Many industries, including metals, petrochemicals, and papermaking, are facing immediate regulatory control of these hazardous chemical emissions under the CAAA's air toxics provision. Electric utilities were exempted from the requirements pending several detailed studies by the EPA and other federal agencies. In fact, the EPA's electric utility emissions risk study is being conducted to determine whether further regulation of the utility industry is "necessary and appropriate." Even if further control is deemed necessary, the resulting regulations may not necessarily require MACT standards.

EPRI is cooperating with several agencies to conduct industrywide emissions and health risk assessments of potentially hazardous chemicals from fossil power plants to provide information to the federal studies. The EPA's decision as to whether any control measures affecting utility emissions are necessary will be based in part on the results of these studies. The EPA is expected to issue a report detailing its rationale for a decision by late 1995. A related study by the agency of mercury emissions from all sources—including their environmental fate, their human health effects, and the cost and availability of potential control technology—is expected to be completed in advance of the utility emissions study.

Research projects initiated by EPRI's Environment Division include the comprehensive PISCES (Power Plant Integrated Systems: Chemical Emissions Studies) project. PISCES is designed to evaluate the complete pathway of trace substances within the power plant itself—from their source in fuel, through the combustion process, to their emission from the stacks. Other EPRI studies are addressing the fate and effects of these substances beyond the stack—their transport, dispersion, ecological pathways, and health risks. Results of these latter studies are being brought together under the CORE (Comprehensive Risk Evaluation) project.

A major part of the assessment—field sampling of utility emissions of trace substances—has now reached a critical phase. After more than three years of measurement and analysis at power plant locations, researchers have begun reporting some preliminary results to the utility industry as well as to the EPA. An interim synthesis report containing many of the results of EPRI's chemical emissions field monitoring, plus case study examples of the approach being used to assess the risks posed by various trace chemicals in power plant emissions industrywide, was prepared for the EPA and presented to utility members in a series of seminars last December.

The field sampling targeted nearly two dozen of the hazardous air pollutants designated by the CAAA. The bottom line from the sampling, according to Ian Torrens, director of the Environmental Control Systems Department in EPRI's Environment Division, is that "most hazardous air pollutants emitted from utility power plant stacks are present in extremely low concentrations, sometimes at or below the limit of detection. The concentrations are so low, in most cases, that the risk to human health cannot be accurately determined." Researchers say that such uncertainty results both from the high variability of measured quantities of chemicals at the level of detection and from incomplete knowledge of the exact species of chemicals that can be present.

Nevertheless, congressional and regulatory pressures to substantially reduce virtually all industrial emissions of hazardous air pollutants like arsenic, chromium, formaldehyde, and mercury mean that even the very low concentrations of such chemicals in fossil power plant waste streams require close examination. "Whether and how to manage these substances may be a new challenge for the electric utility industry," says Torrens.

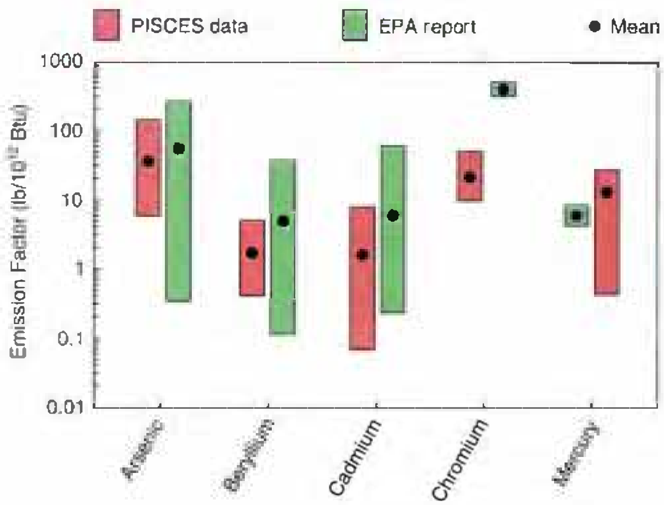
Should EPA risk assessments warrant new controls on utility emissions, the information about the performance of existing control systems will be of crucial importance. PISCES has revealed the rather substantial effectiveness of conventional emissions control systems—electrostatic precipitators (ESPs), fabric filter baghouses, and flue gas scrubbers—in reducing emissions of many hazardous air pollutants along with the ash or sulfur they were designed to capture. Sampling data often show more than 90% (in some cases, over 95%) removal of most chemicals of potential concern to utilities from the flue gas of coal-fired plants equipped with ESPs and wet limestone scrubbers.

"If a plant has good particulate control equipment, you can stop most of the trace metals from coming out of the stack," says Torrens. "And we are making progress in identifying other methods of reducing chemical emissions. For example, we are conducting pilot-scale work on the injection of activated carbon to assess its potential for reducing mercury emissions, in case it is determined by the EPA that such additional measures are necessary and appropriate."

Utilities aren't the main focus

Electric utilities are not the primary focus of the air toxics provisions of the CAAA. According to a report prepared for the EPA before the passage of the amendments in 1990, utility boiler emissions of four potential cancer-causing hazardous air pollutants (arsenic, cadmium, hexavalent chromium, and formaldehyde) pose insignificant risks—estimated at less than one excess cancer a year for a population of 200 million. But that 1989 risk estimate

EMISSION FACTORS FOR SOME KEY TRACE CHEMICALS
Of the 189 hazardous air pollutants targeted by the 1990 Clean Air Act Amendments, EPRI's PISCES program has been conducting power plant sampling of up to 22 key chemicals of interest to electric utilities. The ranges of emission factors observed for five trace metals at power plants firing bituminous coal and equipped with electrostatic precipitators are compared with the ranges reported in a 1989 study conducted for the Environmental Protection Agency. (Note the log scale, with a factor-of-10 difference between numbered hatch marks.) EPRI's PISCES sampling and analysis program generally found lower mean values and smaller ranges of emission factors than had previously been reported in the literature.



developed for the agency was based on chemical emission factors (or estimated rates) from published references with uncertain accuracy and other acknowledged limitations. Because reliable utility emissions data were lacking and the health risk implications of the available data were unclear, Congress stipulated that the EPA conduct a study to determine the public health risks, if any, of hazardous chemical emissions from utility sources.

With field measurements at power plants now largely completed, EPRI researchers are integrating data from various sampling and analytical efforts with results from studies of the environmental transformation of hazardous air pollutants and the human health effects of exposure to them. From this integration will come quantitative estimates of risks associated with the utility industry's share of emissions. The CORE project is continuing, and information from it will form the basis for an updated synthesis report by the industry for submission to the EPA later this year.

The current synthesis studies and field-sampling results reported to the EPA and the utility industry represent the culmination of more than a decade of EPRI research in power plant chemical emissions. Led by the Environment Division, the effort has included research results from a number of Institute programs. Related EPRI research includes an evaluation of potential health effects associated with utility emissions of specific chemicals (for example, arsenic and mercury), a comprehensive study of mercury cycling and ecosystem impacts, and an investigation of the atmospheric transformation of such selected species as mercury.

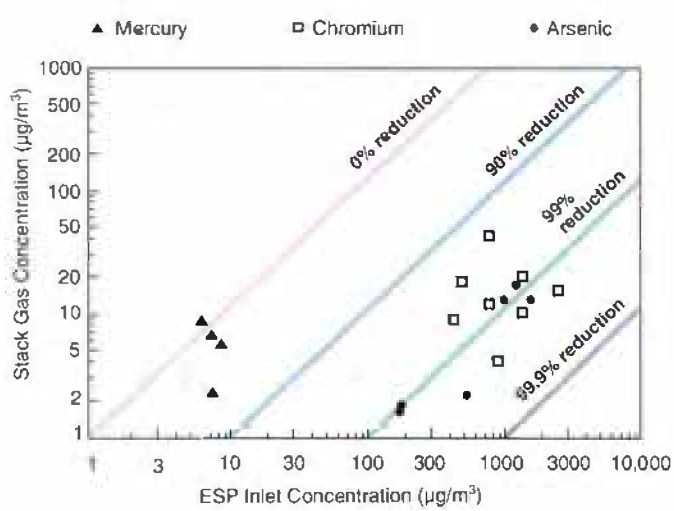
The PISCES sampling effort, launched to fill many of the gaps and resolve uncertainties in published data on utility chemical emissions, has included a range of fossil fuels and conventional boiler configurations as well as a spectrum of emissions control and advanced power plant systems. EPRI has worked cooperatively with the Department of Energy (DOE), the Utility Air Regulatory Group (UARG), and individual utilities to extend the new database to cover more than two dozen power plant sites. "The DOE effort to characterize air toxics emissions will corroborate and complement EPRI's PISCES program," says Charles Drummond, director of the environmental control division at DOE's Pittsburgh Energy Technology Center. "The PISCES test protocol allows us to obtain data that can easily be combined with the EPRI database, providing a comprehensive basis for understanding utility air toxics emissions and the variability between plant types."

According to Winston Chow, who heads EPRI's Waste & Water Management Program and coordinates the PISCES effort, key results from PISCES field monitoring include the finding of generally lower emission factors than those that formed the basis of the EPA's earlier preliminary risk estimate (especially for chromium, manganese, and nickel). The more recent PISCES data also show much less variability at the lower emission factors. The results are considered of sufficiently improved quality to be more representative of actual utility emissions and therefore to be of use in predicting the performance of emissions control systems.

The sampling and measurement data are being incorporated into two other major components of PISCES: a relational database on utility chemical emissions, developed from various sources, and a probabilistic—but user friendly—power plant computer model that tracks the pathways of chemicals and estimates emissions of trace substances. Eventually, EPRI expects to publish one or more engineering reference guides that will include new data on the performance of various control technologies from the recent field-monitoring efforts.

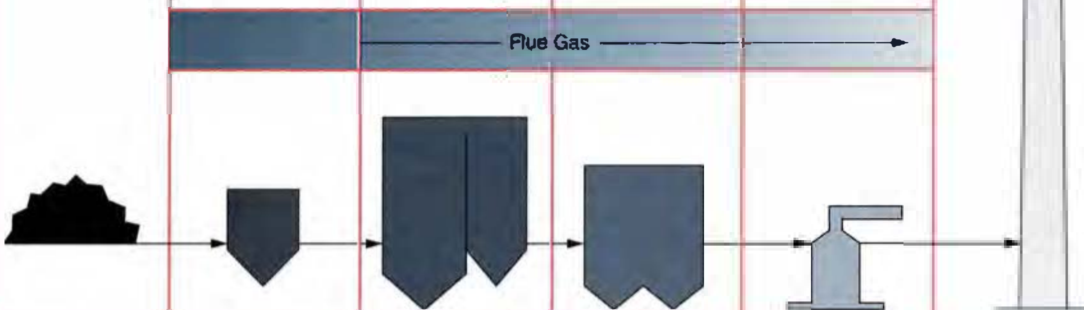
EPRI research managers stress the close, cooperative working relationships that have characterized the interaction with individual utilities, UARG and other industry groups, and government agencies and researchers.

Testimony as to the value of EPRI's chemical emissions studies comes from Charles Goodman, vice president for research and environmental affairs at Southern Company Services and the chairman of UARG: "PISCES is providing crucial information on trace



ELECTROSTATIC PRECIPITATORS REMOVE SOME CHEMICALS WELL **PISCES sampling confirms that some of the important trace chemicals of concern to electric utilities can be effectively removed by existing emissions control systems, such as particulate control devices (electrostatic precipitators or fabric filters) and flue gas desulfurization systems. This graph of data from several PISCES sampling locations shows that ESPs can do an exceptional job of capturing (along with the fly ash from combustion) trace emissions of the heavy metals arsenic and chromium, achieving 90–99% reductions; however, less of the mercury and other volatile trace elements would typically be removed.**

ACCOUNTING FOR TRACE CHEMICAL EMISSIONS: STAGES OF REDUCTION From their widely varying concentrations in different fossil fuels, chemicals of interest in power plant emissions can potentially be reduced as they move along the power generation–flue gas pathway. The degree of emissions reduction possible depends on the power plant design and the emissions control systems installed between the boiler and the stack. This chart shows general emissions reductions at key stages for four representative trace elements; the emission rates are for a 500-MW coal-fired unit and are based on the average concentration of each chemical in Pittsburgh-seam bituminous coal. For many chemicals, coal washing represents the first stage of reduction because some of the chemical is removed with the refuse. Still more is removed with the bottom ash from the boiler, and so on.



Chemical	Raw Coal Emission Rate (lb/h)	Reduction in Emissions				% Emitted
		Coal Washing	Boiler	ESP/ Fabric Filter	FGD	
Arsenic	**0.6812**	65–75%	0–2%	85–99%	0–20%	0–6%
Chromium	**1.1859**	30–75%	3–20%	85–99%	0–20%	0–2%
Mercury	**0.0049**	30–40%	0%	0–60%	10–90%	5–95%
Selenium	**0.0765**	25–50%	0–5%	10–80%	0–50%	20–80%

chemical sources and discharges for assessing the risk from utility emissions of potentially hazardous air pollutants. This effort is helping the industry meet its obligations to ensure the protection of public health and the environment. For example, the field testing we did at our clean coal technology demonstrations is a first step toward providing the industry with information on the air toxics implications of advanced low-NO_x retrofits."

The critical importance of accurate protocols and methods for measuring trace chemical emissions has been highlighted in the PISCES field monitoring. In several cases, EPRI-led advances in the state of the art underlie new insights for the ongoing risk assessment of utility emissions. "We accomplished a number of firsts during the course of the overall effort; in some cases there were no standard methods for measuring the trace substances in utility flue gas," says Chow.

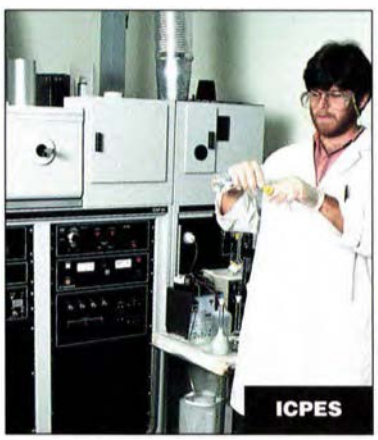
For example, in conjunction with EPA scientists, EPRI evaluated several methods for measuring mercury in power plant waste streams. "This marked the first cooperative evaluation of mercury measurement methods and has led to the only reliable, EPA-accepted approach to such measurement," says Don Porcella, manager of EPRI's mercury R&D. To help utilities design their own chemical emissions sampling programs based on the most up-to-date methods, and to help them understand the capabilities and limitations of the various methods, last fall EPRI published a compendium of techniques for measuring trace substances in flue gas and other power plant process streams.

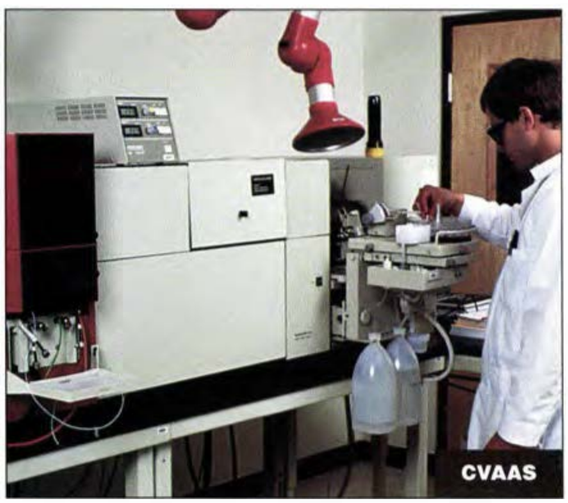
Insights from PISCES field sampling

Over 500 chemicals have been identified in power plant process streams. EPRI's PISCES database contains over 150 megabytes of information, including 80,000 records of reported quantity data from the literature alone. Researchers note that more and better data tend to be available for inorganic species in liquid and solid waste streams than for aerosols.

Despite the amount of information already published and incorporated into early versions of the PISCES database, the lack of fundamental data about the performance of emissions control technologies for the hazardous air pollutants of concern prompted EPRI to undertake the PISCES sampling effort in cooperation with member utilities, utility consortia,

DETECTING TRACE CHEMICALS AT THE LIMIT Many of the key chemicals of concern in power plant emissions are present in concentrations so low that they challenge the capabilities of the most sophisticated and sensitive sampling and analytical equipment currently available to collect, detect, and measure them. EPRI's PISCES sampling effort has employed a number of the latest analytical instruments and has also verified new analytical methods for detecting trace quantities of some chemical species. The table presents some examples of the general detection limit ranges for trace substances in air emissions and the analytical instruments typically used to measure particular chemicals.





Chemical	Detection Limit Range (μg/m³)	Analytical Instrument
Chloride	5–20	Ion chromatograph (IC)
Polycyclic aromatic hydrocarbons	0.40–750	Gas chromatograph (GC), high-resolution mass spectrometer (MS)
Chromium	1.0–5.0	Inductively coupled plasma emission spectrophotometer (ICPES)
Arsenic	0.25–1.0	Graphite furnace atomic absorption spectrophotometer (GFAAS)
Cadmium	0.09–1.0	
Selenium	0.30–1.0	
Mercury	0.14–0.50	Cold vapor atomic absorption spectrophotometer (CVAAS)

Gas sampling from the inlet and outlet ducts of an electrostatic precipitator

and DOE. Emissions and discharges in flue gas and all related solid and liquid waste streams were measured for as many as 22 target chemicals.

In particular, reliable paired data sets (inlet and outlet) for each of the various conventional emissions control technologies were essential as inputs to various models and ultimately for deriving risk estimates that will reasonably account for the emissions reductions many power plants will achieve in the next few years in complying with the CAAA's acid rain provisions. Researchers report that mercury removal by emissions control technologies in use today is particularly difficult to quantify because mercury is typically present in power plant flue gas in concentrations of 1 to 10 micrograms per cubic meter. This fact prompted EPRI's joint measurement methods validation effort with the EPA.

"Comparing the PISCES field-monitoring results with information in the literature reaffirms our understanding of the common fate of certain classes of chemical species within the power plant," says Torrens. "For example, comparing the concentration of chromium in coal with that found in fly ash indicates that a large proportion of chromium is captured with the particulate matter. This suggests that highly efficient ESPs and baghouses would remove chromium and other similarly behaving elements quite efficiently. And our field studies show that chromium concentrations in the stack are quite low." On the other hand, the field-monitoring results for mercury emissions confirm previous literature references and suggest that most of this volatile element remains in the flue gas beyond an ESP.

ESP-equipped coal-fired plants represent the largest segment of types of plants tested under the EPRI and DOE field-sampling programs. The PISCES results confirm the capacity of these particulate control systems to significantly reduce the levels of many heavy metals in flue gas streams. Some metals, including arsenic, cadmium, chromium, lead, and nickel, can be removed with greater than 90% efficiency. The measurement data also indicate that fabric filters can achieve reductions of over 99% for such heavy metals as arsenic.

According to Chow, researchers speculate that such reductions result from the condensation of the metal species on particulate matter as combustion gas temperatures drop from those typical inside boilers to the much lower temperatures at the inlet to particulate control systems. "It appears that conditions that promote lower temperatures and the improved removal of combustion and postcombustion particulates and aerosols also serve to control many of the heavy metals," says Chow. But he notes that the more volatile elements mercury and selenium stand as exceptions and that further research is needed in order to understand their fate and chemical transformation.

Among the various combinations of control technologies examined under the PISCES field sampling, the best overall reduction of trace metals (more than 95%) was achieved with fabric filters alone or with the combination of particulate controls and either wet or dry flue gas desulfurization (FGD).

Mercury removal appears to be higher for flue gas scrubbers than for particulate control systems, researchers say, because mercury may exist partially in an oxidized form (mercuric chloride). Indeed, one of the key insights of the PISCES fieldwork has been recognition of the importance of the oxidation state of individual species of trace elements in determining their ultimate environmental fate or amenability to control measures.

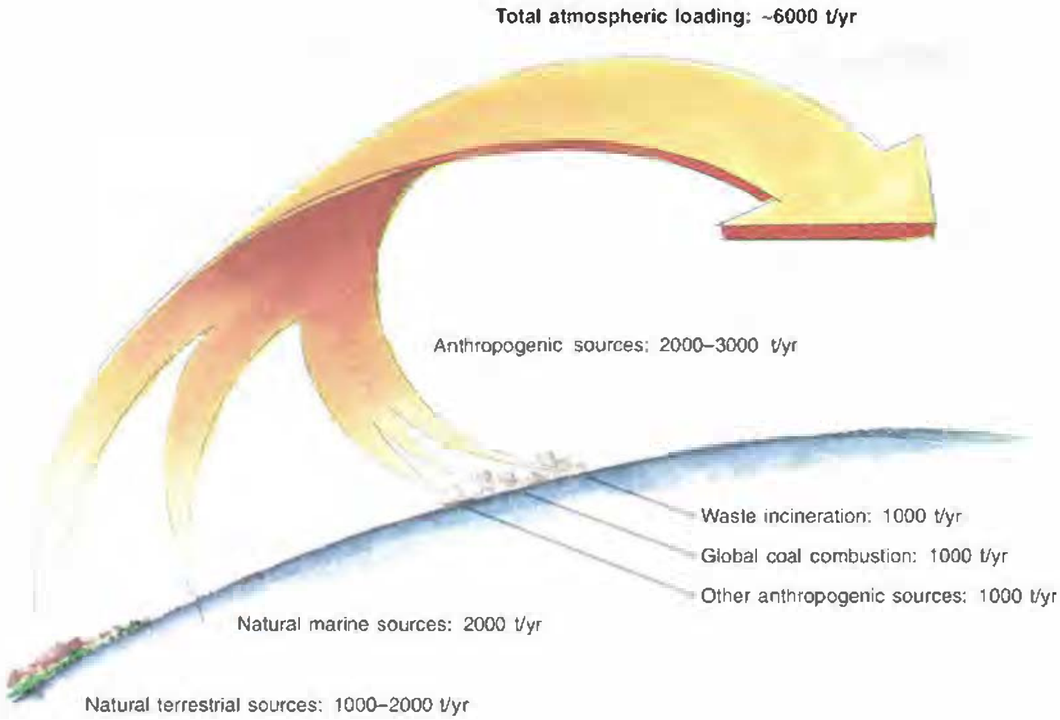
In limited studies involving the treatment of bituminous coal gas in a 4-MW pilot-scale cold-side ESP and a wet limestone FGD system, two prominent species of mercury (ionic and elemental) were found. About 60% of the mercury in the flue gas at this site was in ionic form. In this particular instance, the combination of the pilot ESP and wet FGD appeared to capture all of the ionic mercury but only a small portion of the elemental mercury. Researchers say that the proportion of ionic to elemental mercury tends to vary with location in the flue gas path, coal type, and plant design and operating conditions.

The good material balances between emissions and the levels of chemicals in the fuel noted for most of the key elements measured under PISCES field sampling provide some indication of the reliability of the data. Researchers report, however, that balances for selenium were highly variable, possibly as a result of interferences in the measurement methodologies. In the case of two other metals—chromium and nickel—the emission factors seen were one to two orders of magnitude lower than those reported by the EPA in 1989. Researchers believe that the discrepancy may be explained by the earlier use of stainless steel collection probes, corrosion of which could easily have contaminated samples.

SAMPLING EMISSIONS
The PISCES chemical emissions sampling effort has collected fuel composition data as well as inlet and outlet measurement data for flue gas and solid and liquid waste streams at over two dozen sites. Conducted in collaboration with EPRI member utilities, utility consortia, and the Department of Energy, the PISCES work covered a wide range of fuels and all major types of power plants and emissions control systems.

Hydrogen chloride and mercury

Two of the 22 targeted trace substances measured under the PISCES and DOE field-sampling efforts, hydrogen chloride and mercury, received significant attention during debates on the air toxics provisions of the CAAA, and they illustrate some interesting contrasts in considering the range of utility emissions. Because of its potential to bioaccumulate in the food chain, mercury was a focus as a health risk, while hydrogen chloride came in for scrutiny primarily because of the large quantity of emissions involved. Researchers note that



MERCURY EMISSIONS IN PERSPECTIVE **The contribution of U.S. electric utility power plants to overall emissions of mercury from both man-made and natural sources should be viewed from a global perspective. Of total atmospheric emissions of about 6000 tons per year from all sources, only 1000 tons per year are estimated to come from the combustion of coal throughout the world; of that portion, U.S. power plants contribute about 40 tons per year.**

both are highly volatile substances and that their removal from power plant flue gas is possible to varying degrees.

Because of the relatively high concentration of inorganic chlorides in bituminous coals (the concentration varies widely but averages 0.12%), emissions of hydrogen chloride average about 1400 tons a year for a 500-MW plant without an FGD system. The EPA study will evaluate whether health risks are significant with residual emissions of hydrogen chloride—that is, the emissions estimated to remain after environmental control systems satisfying all other provisions of the CAAA are in place.

During combustion in the furnace, over 95% of the chloride in coal is released, primarily in gaseous form. There is little interaction with the ash because temperatures are above the acid dew point for hydrogen chloride; thus very little HCl is detected in the fly ash regardless of the type of coal. HCl is not considered to be a carcinogen, and no standard exists for either acute or chronic exposures to it. However, the EPA has a recommended reference concentration of 7 micrograms per cubic meter for purposes of public health protection against chronic, long-term noncarcinogenic effects. For a 750-MW coal-fired power plant, the maximum 1-hour ground-level concentration is estimated to be 7.1 micrograms at a distance of 1600 meters from the stack. The computed maximum annual average concentration from the plant would be 0.7 microgram—a factor of 10 less than the EPA's reference concentration. And, if required, existing coal-fired plants equipped with wet or dry FGD can achieve over 90% removal of HCl, as confirmed in the PISCES field sampling.

Mercury, on the other hand, is emitted in relatively small quantities. Uncontrolled emissions from a typical 500-MW coal-fired plant would be about 500 pounds per year. Actual emissions are probably lower, since current environmental control technology removes some mercury. The annual contribution of U.S. fossil-fuel-fired electric utility boilers has been estimated to be less than 1% of total global mercury emissions (from both man-made and natural sources) and less than 2% of the man-made share worldwide. For mercury, as for hydrogen chloride, the overall health risks from power plant emissions may be low. Preliminary health risk estimates at one plant with an ESP and a wet FGD system indicated risks from mercury emissions at three to four orders of magnitude below the hazard threshold. Most of the risk is manifested through the ingestion pathway (i.e., water systems and the food chain) rather than by inhalation.

Mercury levels in U.S. coals vary less widely than do chloride concentrations, although the widespread practice of coal washing to reduce ash content is believed to bring mercury levels for most coals fired in power plant boilers to around 0.1 part per million. Researchers are continuing efforts to determine the dominant form of mercury emitted in combustion flue gas, which they believe may depend on the coal's chlorine concentration and therefore the level of hydrogen chloride. Many of the literature references to mercury emissions from coal-fired power plants are unclear or unreliable because of uncertainties associated with methods of sampling and analysis. Moreover, most of the mercury removal data available before EPRI's PISCES field sampling were from municipal waste incinerators, where concentrations of mercury emissions are typically higher than in utility flue gas by several orders of magnitude.

A review of references in the literature shows mercury removals of 10–50% with fabric filters or ESPs and removals of 30–

80% with FGD systems. The more recent EPRI PISCES data indicate removals of 20–90% for cold-side ESPs; 85–90% reductions were observed in limited measurements from fabric filters. Researchers stress that the results are preliminary and attribute the large ranges to several possible factors: sampling and analytical variability, unburnt carbon carryover that adsorbs mercury, the particular oxidation state of mercury in various flue gas streams, gas temperature, and perhaps the varying chloride content of the fuels.

Although municipal waste incinerators are quite different from power plants in terms of emissions characteristics, there are numerous reports of mercury removal from the flue gas of such incinerators through the use of chemical additives. One company has used activated carbon powder in a spray dryer and lower exit-gas temperatures to improve mercury removal. Data reported for one waste incinerator indicate that a spray dryer–baghouse combination removed 69% of the total mercury without the additive and 91–95% with the injection of activated carbon at lower exit-gas temperatures. The removal factors appear high, researchers note, because mercury emissions from incinerators are typically two to three orders of magnitude higher than those from fossil fuel power plants. Similar results have been reported in a limited number of tests involving the use of activated carbon as an additive for mercury removal at coal-fired power plants.

Recent exploratory tests sponsored by EPRI injected activated carbon just ahead of a 1-MW pilot-scale pulse-jet fabric filter system at a power plant firing subbituminous, low-sulfur coal. Mercury removals of better than 90% were observed at low flue gas temperatures with the injection of 4000 parts of carbon per part of mercury in the flue gas. Without carbon injection, the fabric filter's mercury removal efficiency dropped to 30–50%. Much lower mercury reductions have been observed at gas temperatures in excess of 300°F (149°C).

Recent tests of carbon injection at another U.S. utility burning western subbituminous coal showed no measurable mercury removal, however. Additional research by the electric utility industry and U.S. government agencies is under way to establish the properties of such sorbent injection techniques and their application to mercury removal.

What about organic compounds?

Although trace heavy metals and inorganic acids have been the major focus of attention both from an analytical viewpoint and in terms of their potential for future emissions reduction requirements, EPRI's field chemical sampling efforts have included several volatile organic compounds, formaldehyde, and polycyclic aromatic hydrocarbons. Preliminary EPRI risk assessment case studies appear to indicate that, compared with trace metals, these specific organic compounds in utility power plant emissions pose only a very small risk to human health or to the environment. Their presence is typically at or below the detection limit of current EPA-recommended measurement methods. There are still other organic compounds that have not yet been sampled and measured at power plants.

Evaluating potentially toxic emissions is critically dependent on the ability to sample and measure such species as the various organic compounds, especially when a majority of the chemicals listed in the CAAA have not been measured in power plant waste streams. Without the requisite understanding of the capabilities and limitations of measurement methods, the probability of obtaining misleading results is high. Utilities can therefore expect to realize significant value from applying the methods of measurement described in the EPRI compendium published last fall.

Under the continuing PISCES program, specific methods for measuring important chemicals of concern in fuels and flue gas streams will be addressed in both laboratory development efforts and field evaluation and validation studies. Besides methods for measuring mercury, improved techniques for sampling benzene and for identifying individual oxidation states of such trace elements as arsenic and chromium are of particular interest to EPRI researchers.

Input to decision making

An ultimate end product incorporating results from all of EPRI's research studies in hazardous air pollutants is a series of computer modeling tools and a risk assessment methodology that will allow utilities to evaluate changes in operations and fuel use and to conduct their own multimedia risk assessments in meeting future regulatory requirements. A new comprehensive modeling tool for inhalation risk assessment (known as CRAFT) has been developed, while two other related computer models—AERAM and AirTox—are being upgraded to be more user-friendly and cost-effective. A new multimedia risk assessment model (called TRUE, for total risk of utility emissions) is being tested and will soon be available for general utility use. Over the long term, EPRI managers envision qualifying continuous air toxics monitoring systems when they are developed and become available for key chemical species of interest to electric utilities.

"The research challenge in the analysis of environmental transport, fate, and risk outcomes is to determine whether there's any impact from the chemicals attributable solely to utilities," says Leonard Levin, who directs EPRI's air toxics risk analysis studies. "For example, arsenic in massive amounts is attached to natural dust from the earth's crust; that dust accounts for the majority of arsenic exposure, so determining the effects due to utility emissions alone is consequently more difficult."

Concludes Ian Torrens, "This is a highly targeted R&D effort to provide information never before available on electric utility trace substance emissions and the risks that could ensue from them. The quality of the data we are obtaining in cooperation with DOE, UARG, and the EPA will help utilities judge their specific role in overall emissions of these substances and will provide a better basis for society to judge the risks and assess the need to reduce them further." ■

Background information for this article was provided by Winston Chow, Leonard Levin, and Ian Torrens, Environment Division.

by Leslie Lamarre

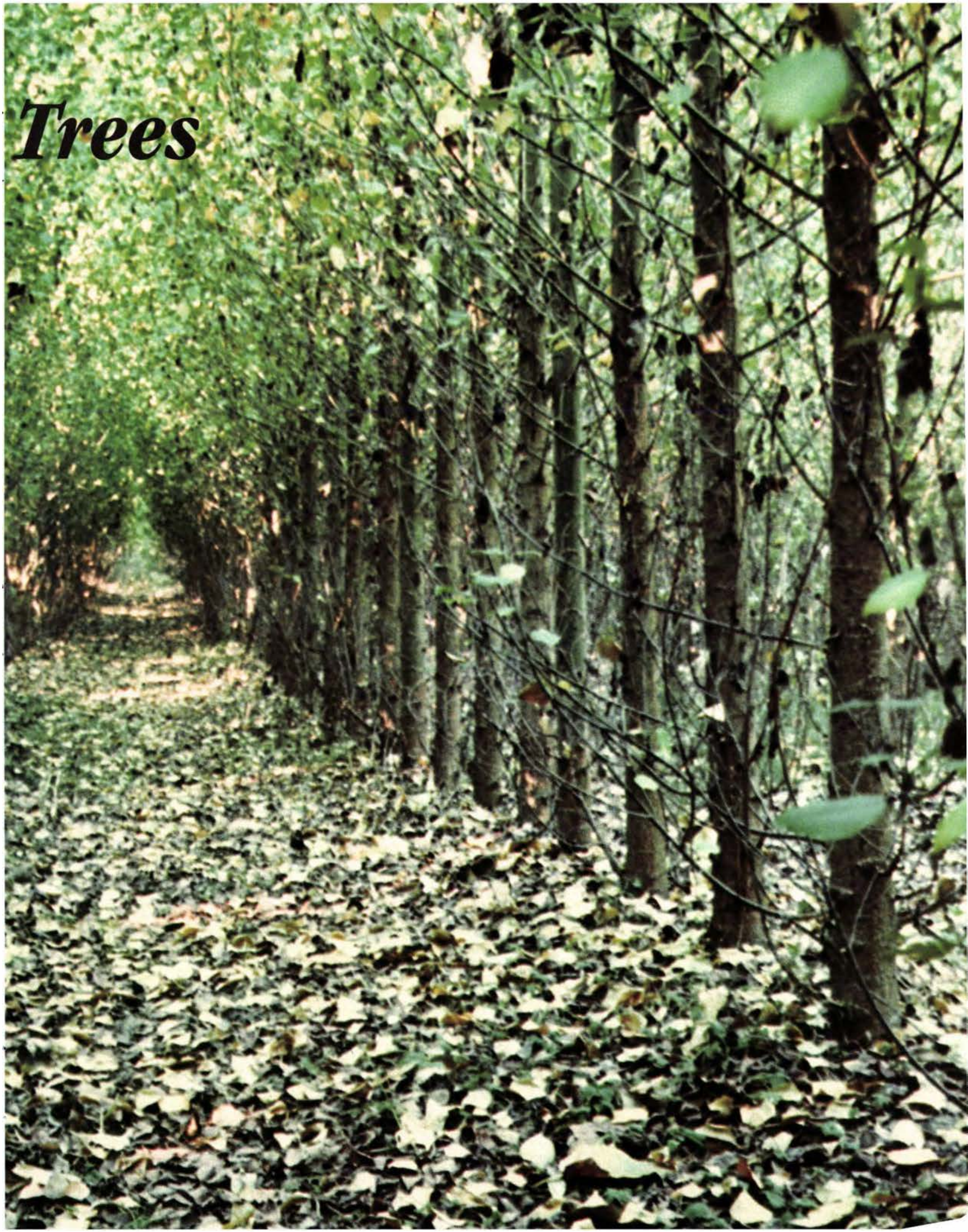
Electricity From Whole

THE STORY IN BRIEF Experimental plantations of fast-growing hybrid poplar trees in the Midwest may one day fuel a new type of electricity generator. Called Whole-Tree-Energy technology, this system would produce electricity by burning sections of whole trees that have been dried in an air-supported fiberglass dome. Although it is still under development, Whole-Tree-Energy technology appears to be a cost-competitive alternative to coal-fired power production. The technology offers relatively low emissions of sulfur dioxide, nitrogen oxides, and particulates, and when fueled by a renewable tree crop, it releases no net carbon dioxide into the atmosphere. Two midwestern utilities have joined EPRI in a study of the feasibility of establishing the world's first Whole-Tree-Energy power plant.

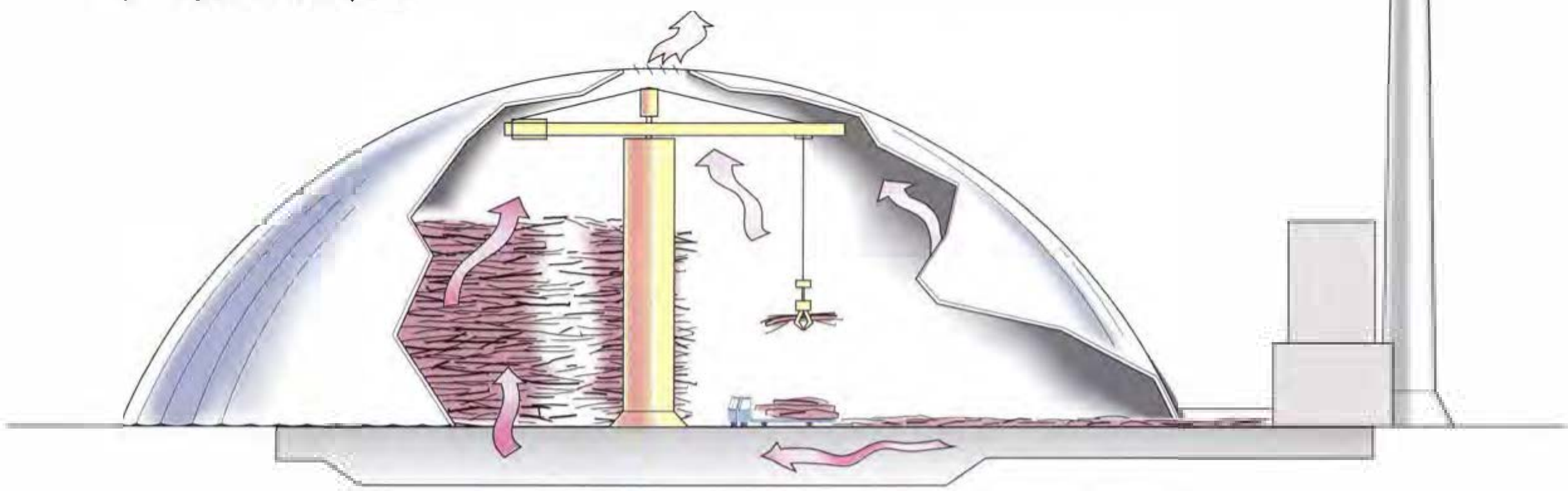
In the rural reaches of southern Minnesota just north of the Iowa border lies a 20-acre patch of poplar trees. In the springtime, when the branches are thick with new leaves, the tract could pass for a natural forest. But autumn provides a clearer view, revealing that the trees are planted in evenly spaced rows, much like the rows of corn that once occupied the same site. Indeed, this is not a forest but a plantation. And the trees are a fuel crop that may one day feed an electricity generator.

This experimental field of fast-growing poplar hybrids in Fairmont, Minnesota, is one of many established in the Midwest as a potential fuel source for a new electric power generation technology still under development. Called Whole-Tree-Energy™ technology—because it literally involves the combustion of whole trees—this patented innovation appears to be an

Trees



DOME-DOMINATED DESIGN **The air-supported fiberglass dome used for reducing the moisture content of freshly harvested whole trees is significantly larger than the power plant that turns the trees into electricity. Inside the dome, the specially designed whole-tree stacker, consisting of a tower crane and grapple, removes whole trees from the trucks that deliver them from nearby plantations and stacks them in a large, circular structure to a height of more than 100 feet (30 m). Waste heat is piped from the plant into the dome for drying, entering the structure from beneath the tree stack. EPRI estimates that tree plantations adequate to supply a 100-MW plant would occupy less than 7% of the land within a 25-mile (40-km) radius of the plant.**



attractive alternative to fossil-fuel-fired power production: it is a renewable energy technology that offers environmental benefits at an acceptable cost, without the need for the expensive sulfur dioxide (SO_2) emissions control equipment required for many coal-fired power plants.

Conceived by a power plant superintendent in 1978, Whole-Tree-Energy technology involves the combustion of tree crops from farms distributed within a 25-mile (40-km) radius of a given plant. Harvested and delivered whole, the trees are dried in an air-supported fiberglass dome structure over a 30-day period by using waste heat from the combustion process in the adjacent plant. Trees leave the dome on a conveyor, and, at the boiler wall, batches are cut into sections to fit the boiler. In the case of a 100-MW plant, these sections are about 28 feet (8.5 m) long.

Like other biomass fuels, such as perennial grasses, trees have the potential to be neutral in terms of carbon dioxide—that is, to emit no net CO_2 into the atmosphere. This is because the level of CO_2 emitted in the combustion process is essentially equivalent to that absorbed by the fast-growing tree crop. "In areas of the country that are not arid or semiarid, this technology offers the opportunity for cost-effective solar energy despite cloudy climates," says Evan Hughes, EPRI's manager for renewable fuels. "The trees capture and store energy from the sun."

Also like other biomass fuels, trees and clean wood release low levels of nitrogen oxides (NO_x) and ash during the combustion process. And the levels of SO_2 released by wood are even lower than those released by other biomass fuels and are sometimes not even measurable. A 1986 test sponsored by Northern States Power Company that measured uncontrolled emissions of SO_2, NO_x, and particulates from the combustion of whole trees found the emissions to be lower than those resulting from pulverized-coal plants employing expensive emissions removal systems. Also, trees and other clean biomass feedstocks do not release toxic air emissions, such as heavy metals.

The Whole-Tree-Energy concept has been developed and tested over the years with support from EPRI, Northern States Power, and other organizations. Recently Minnesota Power and Wisconsin Power & Light Company joined forces with EPRI to study the feasibility of establishing the world's first whole-tree power plant, a 100-MW facility. "The concept of feeding wood in the form of whole trees to a boiler is a new twist on an old idea," says Hughes, who manages EPRI's work on the technology. "Many people think burning wood is dirty. Out of a fireplace, wood smoke is dirty, but out of a power plant that accepts clean wood as fuel and employs state-of-the-art combustion technologies, it's very clean."

Planting the seed

David Ostlie, the power plant superintendent who invented and patented whole-tree technology, says he was building his house in a wooded, newly populated area of central Minnesota when he first came up with the idea of pursuing clean wood-burning electric power generation. Every house in the neighborhood had either a fireplace or a wood stove. And in the chilly winter months, these were fed regularly with wood that had been cleared for driveways. Before long, the smoke became a nuisance. "Not only could you see it, but it was tough to breathe," says Ostlie.

Ostlie, who worked for Northern States Power, knew enough about electricity generation to do some experimenting on his own. Using skills retained from his days as an ironworker, he designed and built a combustion unit about the size of a large home freezer in his spare time, then installed and tested it in the equipment storage area beneath his three-car garage. Fueled with the same oak logs his neighbors used in their fireplaces, the unit produced a clear exhaust, proving that it could burn the wood cleanly and efficiently. According to Ostlie, the absence of soot in the exhaust indicated that the unit generated very low levels of aromatic hydrocarbons, the cancer-causing emissions contained in the smoke released from typical residential fireplaces. The unit was also able to burn the wood completely, leaving no unburned carbon (usually indicated by remaining cinders). The secret, Ostlie says, is to use dry wood and a high temperature.

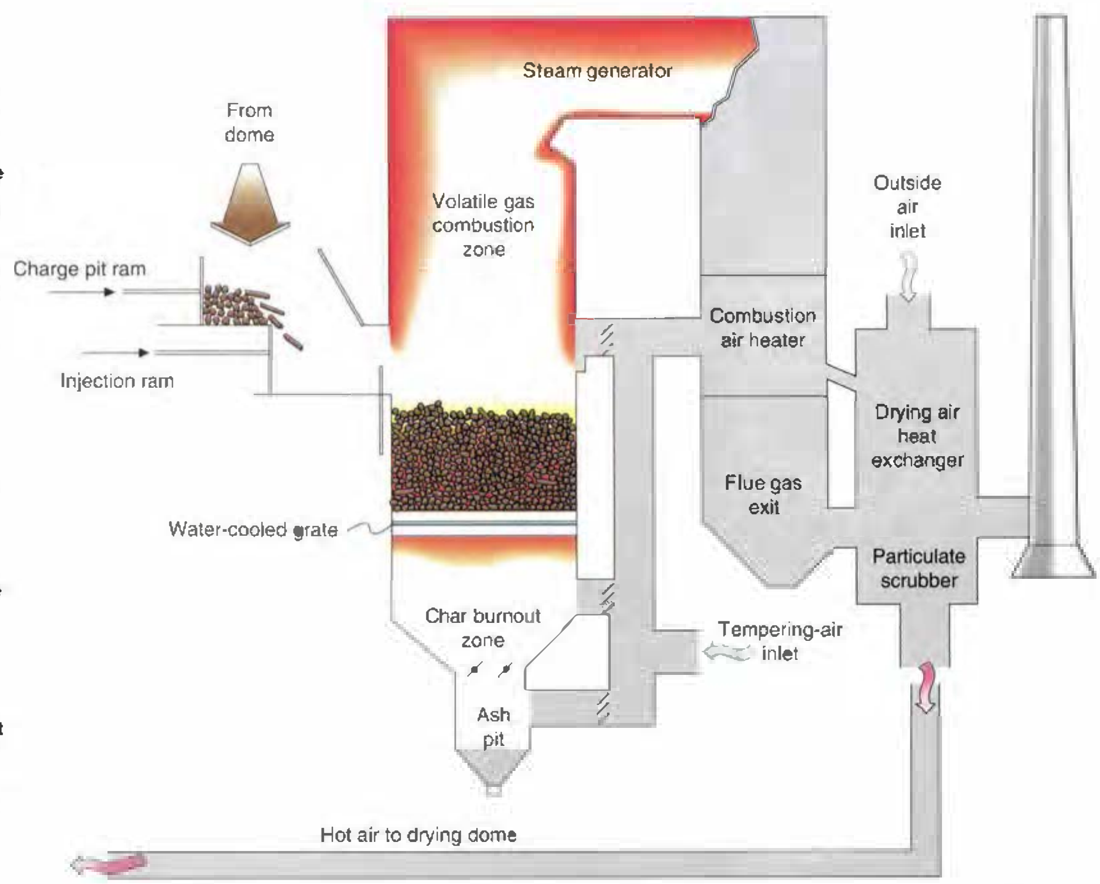
Not only did Ostlie's tests prove that wood could be burned cleanly, but they also introduced a new concept: burning wood in relatively large sections. "Having some knowledge of the electric power industry, I knew that the few existing wood-burning power plants used chipped or shredded wood," he says. "I was also aware that the process of breaking wood down to this size is expensive. Being able to avoid these costs would be a great advantage." (An EPRI study has since shown that eliminating the chipping process can save about 35% of the cost of harvesting and handling the fuel before it arrives at the plant.)

By 1984 Ostlie was ready to progress to the next step. He developed a slide show and a schematic of the concept and presented them to managers at his utility. He also talked with outside organizations he thought might be interested, including St. John's University in Collegeville, Minnesota. St. John's was the first to step forward, allowing him to use a 1.6-MW boiler for testing. Feeding the unit 4-foot-long (1.3-m) tree sections, Ostlie was able to attain a high enough temperature and heat release rate to allow an efficient superheat cycle typical of the largest coal plants in the country. "We could have gone beyond the 2400°F [1590 K] we achieved," he says. "Our limitation was not the fuel but the boiler itself."

The next test, conducted at Northern States Power in 1986, used a formerly coal-fired 10-MW unit that was converted to accept wood fuel. The challenge for this experiment was to reach an output equivalent to 30% of the full capacity, which would indicate that the technology could succeed on a utility scale. Ostlie managed to achieve an output equivalent to 90% of the full capacity, or 9 MW, and maintained an average output of 6–7 MW during sampling periods throughout the 100-hour test.

Just as significant were the favorable data on emissions. "At the time, the Environmental Protection Agency said the NO_x levels were the lowest ever measured for solid fuel in the United States," Ostlie notes. This did not come as a complete surprise, since clean wood contains only about one-fourth the nitrogen of an average coal, and conventional wood-fired plants generally emit 45% less NO_x than coal-fired units. SO_2 emissions from the test were almost unmeasurable, being far below the levels set by air quality regulations. Because clean wood has such a low sulfur content (at least five times lower than that of a low-sulfur coal), a very low SO_2 level can be achieved without the aid

FROM TREES TO ELECTRICITY
After whole trees leave the drying dome on a conveyor, they are cut into sections—about 28 feet (8.5 m) long—that will fit in the boiler chamber. A ram pushes the trees into a charge pit, and a second ram then pushes them into the furnace. A Whole-Tree-Energy boiler is taller than a gas-fired boiler but is otherwise very similar. The greater height helps achieve a high heat release rate as well as complete combustion, allowing space for carbon, hydrogen, and other gases to burn off. Cinders from the burning bed of trees fall through a grate and into an area called the char burnout zone, where any remaining carbon in the material burns away. To promote complete combustion, air is fed into the boiler both below and above the bed of trees. Waste heat from the flue gas is captured by a heat exchanger for use in the drying dome.



of the costly SO_2 removal systems used at many coal plants. Particulate emissions in the 1986 test were also low, even without the aid of a particulate collection device. This is due primarily to the low ash content of wood, which is typically between one-twentieth and one-tenth of the ash content of coal.

Forging ahead

Moving into the next phase of development was not easy. Although the favorable tests impressed managers at Northern States Power, the utility decided not to invest immediately in the further development of this technology. Ostlie, who was committed to making his concept a reality, established his own company in Minneapolis—Energy Performance Systems, Inc. (EPS)—and sought support for the technology's development from other organizations, including EPRI.

At the time, EPRI was just starting to revive its biomass research program, and the idea of an efficient, low-cost combustion technology fueled by a fast-growing tree crop was attractive. EPRI conducted an engineering and economic evaluation of the technology and, on the basis of the results, which were released in 1991, agreed to support its further development. EPRI and EPS then jointly conducted a field test in the town of Aurora (population 3000) in northern Minnesota. The test demonstrated the processes of harvesting, transporting, stacking, drying, and combusting whole trees—some 3000 tons worth.

Standard logging trucks each carted about 25 tons of whole trees to the demonstration site. A stacking system that Ostlie designed, consisting of a tower crane and a remotely controlled grapple, piled the whole trees into a square stack about 70 feet (20 m) on each side and more than 100 feet (30 m) high at its peak. Researchers monitored the structure throughout the stacking and unstacking process and tested its stability by using a bulldozer to pull on a ⅝-inch-thick (1.6-cm) cable that was connected to a steel beam inside the full stack. Ultimately the cable snapped, but there was no noticeable movement of the stack. In fact, Ostlie says, there are no obvious limitations to extending the stack upward another 50 feet (15 m).

The test crew wrapped the vertical sides of the chimney-shaped wood stack with a tarp. The idea was to simulate the wind-sheltered environment integral to the whole-tree drying process conceived by Ostlie, in which trees would be dried inside an air-supported fiberglass dome structure. In an actual WholeTree-Energy plant, waste heat from the combustion process would be used to dry the trees. For the test run, air at about 130°F (330 K), roughly the temperature of the air that would be diverted from an actual whole-tree plant, was delivered by duct to a distribution manifold below the tree stack. In a 30-day period, the moisture content of the trees was reduced from 44% to 20%; over 700 tons of water, or about 68% of the original moisture in the trees, was evaporated.

The combustion tests were equally successful, demonstrating that the combustion of 8-foot-long (2.4-m) tree sections can produce a heat release rate high enough for an efficient generation process. The tests produced an average heat release rate of 3.2 million Btu per hour per square foot (10 $MWth/m^2$). One experiment resulted in more than 4.2 million Btu per hour per square foot (13 $MWth/m^2$)—a record for wood-burning combustion units, Ostlie says. By comparison, a typical coal-fired boiler has a heat release rate of approximately 2 million Btu per hour per square foot (6 $MWth/m^2$), while boilers fired by wood chips typically have rates below 1 million Btu per hour per square foot (3 $MWth/m^2$). According to Hughes of EPRI, who oversaw the test, the factors contributing to the high heat release rate include the large amount of wood in the boiler, the high temperature, and the reduction of the moisture content to below 25% before combustion.

The Aurora tests, completed in the summer of 1992, simulated only the lower portion of the boiler. Above the bed of burning trees, a whole-tree boiler would be similar to boilers built for the firing of natural gas. The exception is that the upper portion of a whole-tree boiler would be taller—80–110 feet (24–34 m)—in order to achieve complete combustion as well as a high heat release rate.

A whole-tree boiler has three combustion stages. The first occurs in the bottom of the boiler, where the burning process drives volatile gases out of the wood. In the second combustion stage, hydrogen, carbon monoxide, and other gases released during the combustion and gasification of the solid wood burn in the tall portion of the boiler above the bed of trees to become water vapor and CO_2, both of which escape into the atmosphere. In the third and final combustion stage, any carbon that's left as char in the bottom of the bed is burned completely, also becoming CO_2. To help ensure complete combustion and low NO_x formation, air is fed into the boiler both beneath and above the bed of trees. The boiler's height allows enough space to stage the introduction of overfire air, helping to optimize NO_x reduction.

Research under way at the University of Wisconsin at Madison, headed by Ken Ragland, a professor of mechanical engineering, will help determine the most effective design and operating conditions for whole-tree boilers. Ragland is developing a computer model, based in part on data from combustion tests sponsored by EPRI. The model will take into consideration such given factors as fuel moisture and fuel size, in order to predict heat release rate, fuel feed rate, and the ratio of underfire to overfire air necessary for best results.

A new plant?

Encouraged by the positive results of the Aurora test, two EPRI member utilities, Minnesota Power and Wisconsin Power & Light, approached EPRI and EPS about exploring the feasibility of building a WholeTree-Energy plant in the upper Midwest. "From a utility perspective the one feature that differentiates this technology from the other renewable options is that a WholeTree-Energy plant is fully dispatchable—that is, available anytime, regardless of unfavorable weather conditions," says Van Nast, one of WP&L's representatives on the team managing the joint study. "The same cannot be said for such options as wind and solar."

TREE CROPS This aerial view of a hybrid poplar test plantation in Howard Lake, Minnesota, shows tree growth after two years. Typically, such crops can be harvested after seven years of growth, at which time the trees are approximately 50 feet (15 m) tall. New tree crops can be planted on fields that have been harvested, or trees can be allowed to grow naturally from the remaining stumps.

EPRI agreed to join the utilities in funding such a study. This ongoing investigation includes a cost and feasibility evaluation by an architectural engineering firm, as well as an examination of potential fuel resources and possible plant sites. Final results are expected by early 1994. If these results show that a 100-MW project is feasible and cost-effective, the new plant would be brought on-line by 1999.

The demonstration plant would not be the first wood-fired electricity generator in the country; several hundred already exist. Most of them are owned by paper companies and saw mills, which burn their own scrap wood to generate heat and electricity, primarily for on-site use. It is increasingly common for these companies to sell excess electricity to utilities. In fact, electricity sales have motivated the construction of a number of these plants in recent years. Only seven of the country's wood-fired plants are actually operated by utilities. These plants are located in Oregon, Vermont, Washington, and Wisconsin. In all, some 5000 MW of power plant capacity in the United States is fired by wood fuel. The utility-owned total is less than 300 MW.

Existing wood-fired generators, fueled by chipped wood with a relatively high moisture content (about 45%), are smaller in capacity and much less efficient than would be the systems designed to use dried whole trees with a moisture content below 25%. The biggest of the existing generators is 50 MW, and most are around 20 MW. Moreover, as EPRI's Evan Hughes explains, WholeTree-Energy technology offers higher efficiencies than plants fired by chipped wood not just because of greater plant size and drier fuel but also because it employs high-pressure, high-temperature steam.

Whole-tree fuel is less expensive than chipped wood. Today, according to Oak Ridge National Laboratory, average prices for wood chips produced for paper making range from $2.60 per million Btu ($2.46/GJ) in the southeastern United States to $6.20 per million Btu ($5.88/GJ) in the Pacific Northwest. Chipped wood intended for fuel purposes would cost less, since—unlike the case with pulp wood—removing limbs and bark would not be necessary. Also, tree growers supplying a biomass market could opt for faster-growing species, which would help bring costs down.

Given these cost-saving factors, Oak Ridge researchers estimate that chipped wood from fast-growing tree farms in the upper Midwest would cost between $2.50 and $2.90 per million Btu ($2.37–$2.75/GJ) if sold today. "Moreefficient harvesting technology, as well as genetic improvements increasing yields to 7 dry tons per acre per year, could bring costs down to less than $2.00 per million Btu [$1.90/GJ] within the next decade," says Lynn Wright, a researcher with Oak Ridge. Whole-tree fuel, which does not have to be chipped, is expected to cost about 37¢ per million Btu (35¢/GJ) less, according to EPRI's studies, says Hughes. "Since tree farmers today can get subsidy payments from the federal government for setting aside former cropland and planting trees to protect it from soil erosion, another 30–60¢ per million Btu (28–57¢/GJ) can come off the cost of wholetree fuel," he says.

Even at this potential subsidized price of $1.20–$1.80 per million Btu ($1.14–$1.71/GJ), whole-tree fuel from dedicated plantations will be more expensive than coal, which can often be purchased for $1.25 or less per million Btu ($1.18/GJ). The higher cost of whole-tree fuel is due in part to wood's significantly lower heating value—about 4500 Btu per pound (10,500 kJ/kg), assuming a typical green wood moisture content of 45%, versus 10,000 Btu per pound (23,000 kJ/kg), on average, for coal. But lower capital costs and operation and maintenance costs are expected to make electricity from Whole-Tree-Energy technology competitive with that from conventional coal technology. In addition, potential tax credits, such as

WHOLE-TREE-ENERGY FIELD TEST **EPRI and Energy Performance Systems worked together to field-test the Whole-Tree-Energy process. Conducted in northern Minnesota, the test demonstrated the harvesting, stacking, and drying of some 3000 tons of whole trees, as well as the combustion of 8-foot (2.4-m) whole-tree sections taken from the stack. Researchers determined that the trees could be stacked safely to heights of over 100 feet (30 m). To simulate the wind-sheltered drying environment of an actual plant, researchers wrapped the vertical sides of the wood stack with a tarp. A 30-day drying period reduced the trees' moisture content from 44% to 20%. Combustion tests showed an average heat release rate (per square foot of furnace space) 60% higher than that of a typical coal-fired boiler.**

those resulting from the National Energy Policy Act for the use of renewable generation technologies, could add to the economic attractiveness of whole-tree technology. As Hughes notes, the 1.5¢/kWh production tax credit in that act would be equivalent to fuel cost savings of $1.50 per million Btu ($1.42/GJ) at the 10,000-Btu/kWh heat rate (34% thermal efficiency) targeted for a whole-tree power plant.

Naturally, the use of existing trees would in many cases significantly lower the cost of electricity production. "The overage, diseased, and otherwise unmarketable portions of existing forests could be targeted as a transitional fuel resource until such time as a dedicated fuel supply from tree plantations is available," says Paul Johnson of Minnesota Power, the former chairman of EPRI's biomass working group. "Removal of this wood from existing forests would likely improve forest productivity and management." However, the prospect of this practice has raised concerns about the overharvesting of higher-quality native forests.

In any case, the key environmental advantage of CO_2 neutrality can best be attained by using renewable tree crops. As one EPRI report puts it, "While the [Whole-Tree-Energy] system can use wood from overage, declining forest stands, and woody residue from existing logging operations, the optimum environmental benefits of the system will be derived from the use of trees grown as a crop dedicated for use as a power plant fuel."

Pulp and paper companies in the Pacific Northwest have pioneered research on fast-growing hybrid poplars. Over the past 15 years, Oak Ridge National Laboratory, in conjunction with the U.S. Forest Service, has built on this industry's findings and on federally supported tests of fast-growing trees in order to develop new techniques for raising hybrid poplars. The 20-acre (8-hectare) plantation in the southern Minnesota town of Fairmont is just

one of dozens of experimental tree plantings established in the Midwest. With funding from EPRI, David Ostlie is now leasing this site, among others, from local farmers to learn more about the fast-growing poplars. Now only seven years old, the Fairmont trees are roughly 50 feet (15 m) high and 7 inches (18 cm) in diameter.

Trees, please

Raising tree crops is a difficult task, since the trees require much attention in the first two to three years. "You can't just plant these trees like a forest and then walk away," explains Wright of Oak Ridge National Laboratory. "If you don't treat these trees like an agricultural crop, they won't survive." Part of the research under way at Oak Ridge will determine the optimal weed and pest control procedures, spacing, and other requirements for a high-yield crop. In drier parts of the country, the trees may even need irrigation.

High-yield crops are not the only concern. As experts involved in EPRI's efforts explain, there are many infrastructure issues to address, including the logistics of establishing an entirely new market for whole-tree fuel. Also, environmental issues, such as the impact of the tree crops on existing species, are not well understood at this time.

In an effort to get a better handle on these issues, EPRI is sponsoring the planting of 1000 acres (400 hectares) of hybrid poplar trees near Alexandria in west central Minnesota. Through this project, organized by the Minnesota Department of Natural Resources, farmers are signing up to plant the fast-growing poplars on their idle farmland—trees that could, but will not necessarily, supply the nation's first Whole-Tree-Energy plant. "We're in the early stages of creating a private-sector vending system to nurture the trees over the years it takes for them to become established," says Thomas Kroll, a manager of the project and a forester with the Minnesota Department of Natural Resources. "This is an entirely new business, raising many issues that need to be sorted out." The vending system will rely on the equipment and service rental systems now employed for traditional crops in the Alexandria region.

Already, some 30 farmers with lots ranging from 10 to 160 acres (4–64 hectares) have signed up for the program. Most of this land is already involved in the federal government's Conservation Reserve Program (CRP), through which farmers are paid to retire highly erodible farmland and preserve it for a 10-year period. Farmers can extend their 10-year contracts to 15 years by planting trees on the land, which helps ensure that the acreage will not be revived for food production. While the CRP wasn't designed to promote biomass energy, "it provides a real window of opportunity for getting some energy crops established," says Kroll. "Over time, this use of the land would have to pay its own way without support from government programs. But for the initial 1000 acres, the CRP program is a real carrot."

EPRI and the Department of Energy will monitor the treefarming activity and its consequences in order to understand any issues that arise in the 1000-acre project. Issues to be addressed include the impact of energy crop activity on small wildlife and the tree farms' effect on biodiversity—the variety of plant and animal species within a given region. Hughes expects that biodiversity will be greater in tree farm environments than it is in environments characterized by the cultivation of a single annual crop, such as corn, but less than it is in a natural forest. He points out, however, that plans do not call for replacing natural forests with tree crops but rather for replacing conventional cropland with tree crops.

Helping address environmental concerns are organizations like the National Audubon Society and the Union of Concerned Scientists, which have been involved in planning for this project. "This 1000 acres may be just the start," says Kroll. "I think the potential exists to expand this effort to include more than 5000 acres [2000 hectares] over the course of the next couple of years." At this time it is uncertain whether trees from the 1000-acre project will be used to fuel the country's first Whole-Tree-Energy plant. However, if the plant is built and if any of these trees lie within a 50-mile (80-km) radius of the site, they are likely to be used.

In a separate effort, EPRI joined forces with the National Audubon Society to establish the National Biofuels Roundtable, which aims to address environmental and socioeconomic issues raised by the use of energy crops. Made up of a group of nationally recognized experts, the roundtable is creating principles and guidelines for biomass feedstock development. The outcome of these efforts will be published in a report geared toward developers of biomass energy systems, state and local government officials, environmentalists, and others. The report is expected to be released in February 1994. Jane Turnbull, a biomass project manager at EPRI who helped organize the roundtable, is developing a separate report—a biomass how-to primer—geared toward utilities interested in implementing biomass power production. That report is due out by the end of the year.

How much wood?

How much wood does it take to supply a 100-MW plant? EPRI studies estimate that the figure is about 1000 acres per MW (4 km^2/MW), assuming a yield of 5 dry tons per acre per year, a 34% thermal efficiency (10,000 Btu/kWh), an 80% power capacity factor, and the setting aside of about 20% of the land for habitat or watershed enhancement, roads, or other purposes. According to Hughes, roughly 12,000 acres (50 km^2) would be harvested annually to supply such a power plant, with seven years allowed for the growth of each new tree crop. "This might seem like a lot of land," notes Wright of Oak Ridge National Laboratory. "But on the basis of the percentage of land available, it's a relatively small amount." Hughes notes that—assuming a yield of 5 dry tons per acre per year—a 100-MW plant would use less than 7% of the land within a 25-mile (40-km) radius. Only one-seventh of this 7% would be harvested in any given year. New tree crops could either be planted on the already harvested fields or be allowed to grow naturally from the remaining stumps.

Federal agencies report that there is much surplus cropland available in the country today. This is due primarily to improved efficiencies in farming. "Today, cows produce nearly four times as much milk as they did in the 1930s," says Thyrele Robertson, an economist with the U.S. Department of Agriculture (USDA). "Corn production back then averaged 25 bushels per acre [220 m^3/km^2]. Now we get more than 100 bushels per acre [880 m^3/km^2]. And our productivity is going to continue to increase."

Researchers at the USDA are investigating the potential for using some of the country's idle farmland to grow energy crops, such as grasses and trees. As Robertson points out, raising energy crops could provide a productive use for the farmland currently enrolled in the Conservation Reserve Program, such as that involved in the 1000-acre project. Raising energy crops could also help stabilize soil threatened by erosion, researchers say. According to Turnbull of EPRI, the information obtained through preliminary studies appears favorable for biomass, especially in comparison with conventional crops raised on the same land. EPRI and the Department of Energy plan to work with the USDA to gather more information on soil texture, erodibility, and nutrient balance in relation to energy crops.

Turnbull notes that energy crops not only could help reduce the country's dependence on fossil fuels but also could be a boost to rural economies. The land available for growing energy crops will range from 100 million to 230 million acres (400,000–930,000 km^2) over the next two to four decades, according to estimates released by federal agencies (including the Department of Energy and the Environmental Protection Agency). However, land suitability, irrigation needs, climate, and biodiversity issues would suggest a more conservative projection of 50 million acres (200,000 km^2) over the next two decades, according to EPRI's calculations. Assuming an annual yield of 5 dry tons per acre, which has been broadly demonstrated, this acreage could produce sufficient crops to supply efficient power plants producing 50,000 MW, or roughly 8% of the current total electric generating capacity in the United States.

If power plants bought biomass fuel at an average price of $2.00 per million Btu ($1.90/GJ), the production of these fuel crops would generate $7 billion a year, most of which would go to farmers, truckers, wood harvesters, and others living in the rural areas surrounding the biomass plants. According to Paul Johnson of Minnesota Power, a whole-tree plant would generate an average of 400 jobs for each 100 MW of power capacity, excluding construction jobs.

At this time, EPRI researchers say, whole-tree technology is the most promising of all biomass alternatives available for electricity generation for three primary reasons. First, it relies on wood, a fuel that can be burned in available combustion equipment; in contrast, grass and other juvenile biomass crops cause boiler fouling and slagging because of their relatively high alkali content. Second, the technology is ready for demonstration and does not require further pilot-scale development, as do other, higher-efficiency biomass combustion technologies. Third, the large size and related high efficiency of whole-tree plants offer the potential for low-cost biomass power. Because of its efficiency, air quality, and CO_2 benefits, whole-tree technology has generated interest not just from utilities but also from organizations outside the industry.

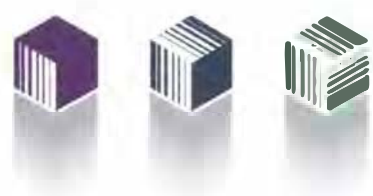
"From our perspective, Whole-Tree Energy is one of the biomass technologies that ought to be evaluated before we consider new coal-fired or nuclear additions," says Bill Grant of the Izaak Walton League, a national conservation organization. He is a member of a task force of experts assembled to review the technical evaluation and site assessment for the whole-tree plant under consideration. "The fact that this technology is net CO_2 neutral is an attractive feature to us. Also, biomass power offers local environmental and economic benefits. This seems clear from the tests conducted so far and from EPRI's evaluation of Whole-Tree-Energy technology."

Grant points out that there are "still a lot of questions pertaining to the growing and supplying of the trees." And researchers like Hughes of EPRI are the first to admit that more work must be done. Still, notes Hughes, "there is no mistaking that the results so far are very promising. Whole-Tree-Energy technology offers the potential for someone today to build a sustainable biomass-fired power generation system—the cleanest solid-fuel-fired power system available on a commercial scale." ■

Background information for this article was provided by Evan Hughes, Generation & Storage Division.

THE INSTITUTE'S MISSION IS TO DISCOVER, DEVELOP, AND DELIVER HIGH-VALUE TECHNOLOGICAL ADVANCES THROUGH NETWORKING AND PARTNERSHIP WITH THE ELECTRIC UTILITY INDUSTRY. RECENT EPRI STAFF AWARDS HIGHLIGHT KEY SUCCESSES FOR 1993 IN ACCOMPLISHING THESE OBJECTIVES.

AWARDS FOR ACHIEVEMENT · 1993 ·



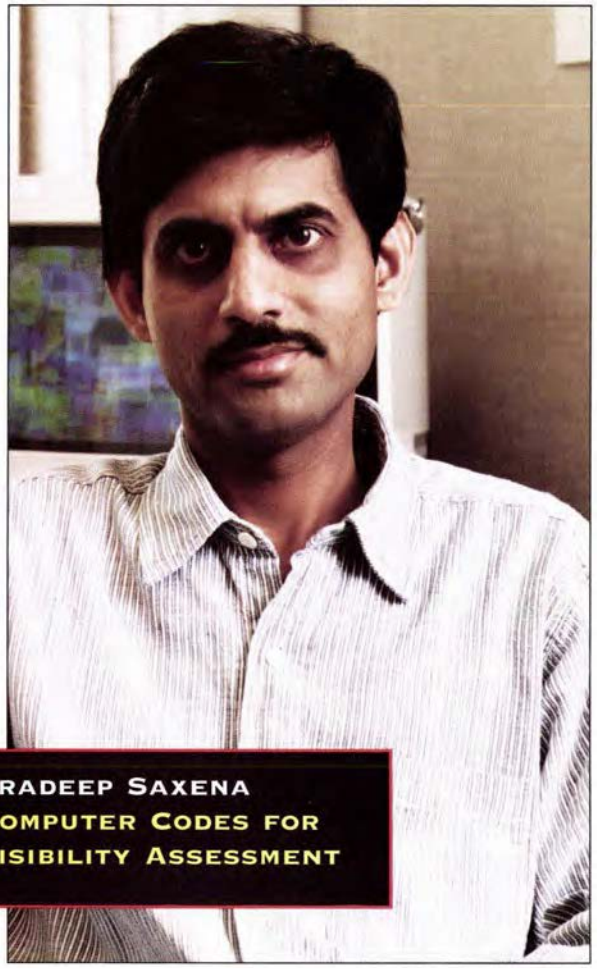
EPRI's Discovery, Development, and Delivery Awards were established two years ago to recognize outstanding staff contributions in each of the major areas that define the Institute's mission. Together, the three Ds embody EPRI's commitment to delivering value to its members as they face increased competition and respond to customer demands for enhanced service. This theme of commitment to excellence in a time of industry change was prominent at the annual Institute recognition program, held in Palo Alto on November 13.

"These awards highlight personal achievements in EPRI's efforts to provide our members with the tools they need to survive in a more competitive environment," EPRI president Richard Balzhiser said in his keynote address. "The accomplishments benefit both utilities and their customers by opening new opportunities to reduce costs and improve service."

Senior vice president Kurt Yeager expanded on this theme. "Our industry is evolving away from vertically integrated, regulated monopolies into a less homogeneous and more competitive structure," he said. "We at EPRI are in the vanguard of this competitive thrust by virtue of our development of technology that helps our customers maintain a competitive position. The development of new competitive technologies can be sustained only through such individual efforts as those we recognize tonight."

The following award-winning accomplishments exemplify EPRI's firm commitment to pursuing the discovery of new ideas through basic research, to transforming these ideas into useful technologies through an orderly development process, and to delivering the final products to members in a readily usable form.

D I S C O V



PRADEEP SAXENA
COMPUTER CODES FOR VISIBILITY ASSESSMENT

For some years there has been a pressing need for a way to mathematically simulate in detail the chemical and physical characteristics of particles suspended in the air and to determine how they form and dissipate. Pradeep Saxena led a group of prestigious investigators at several universities in developing computer codes that could accomplish such a simulation. The codes also model the composition of the particles, their liquid water content, and their light-scattering properties as a function of size.

"Over the next two years," says Saxena, "we'll be improving the codes to add new realism, especially with regard to organic particles, whose behavior in the atmosphere is far less well understood than that of inorganic particles." The contributions of sulfate and nitrate to atmospheric acidity and light scattering are overestimated if organics and water are not included in the analysis.

In the meantime, the codes are being used to estimate the influence of electric utility emissions on visibility in the Grand Canyon and other national parks. ■

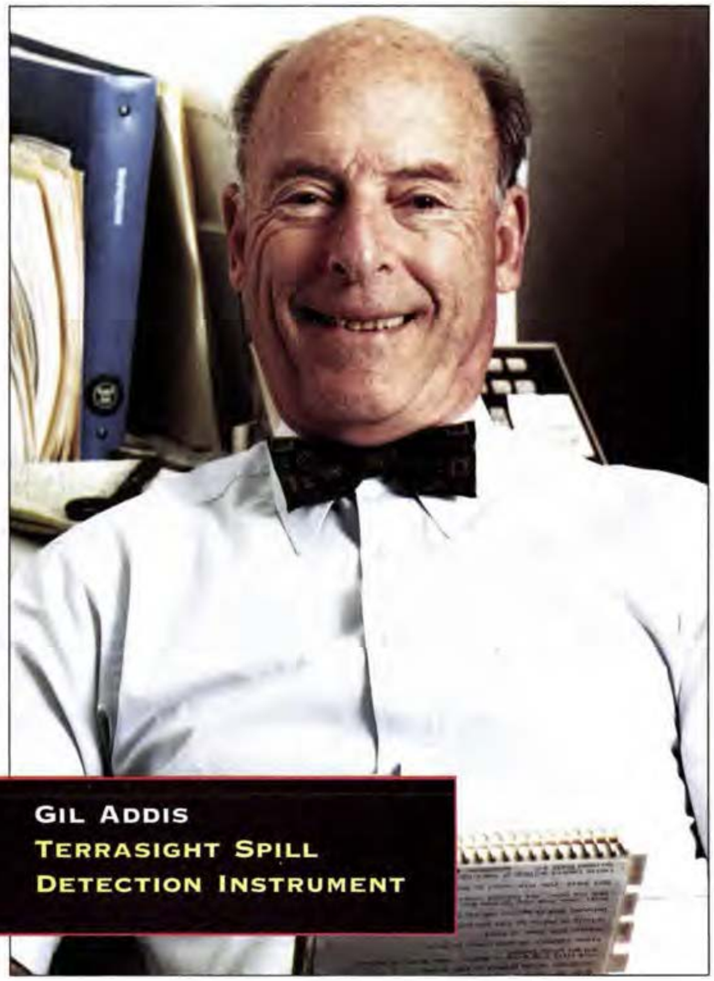
E R Y

MARIO RABINOWITZ
EFFECTS OF AN ELECTROMAGNETIC PULSE

During the 1980s, there was concern that the high-altitude detonation of a nuclear bomb could produce an electromagnetic pulse (EMP) large enough to disable major portions of the North American utility transmission system. Hardening the system to withstand such an EMP would have cost the industry some $10 billion to $100 billion, depending on the hardening criteria applied.

Mario Rabinowitz discovered major flaws in the postulated EMP scenario, finding that the actual effects would be an order of magnitude smaller than had been suggested. At this level, the probability of damage or operational problems resulting from a high-altitude detonation would not be much greater than that of normal operating stresses from switching or lightning events. This discovery saved the utility industry an estimated $10 billion by obviating the need to harden the transmission system against the effects of EMP.

"My original work was focused on the very fast EMP; emphasis had been placed on this pulse because of its large magnitude, although it lasts only about a microsecond," says Rabinowitz. "More recently, there has been speculation about possible serious effects of a much slower pulse called magnetohydrodynamic EMP, which is weaker but has a much longer duration—a couple of minutes. My colleagues and I have published a paper showing that although this pulse might affect large transformers, it wouldn't cause widespread damage to the U.S. power grid." ■



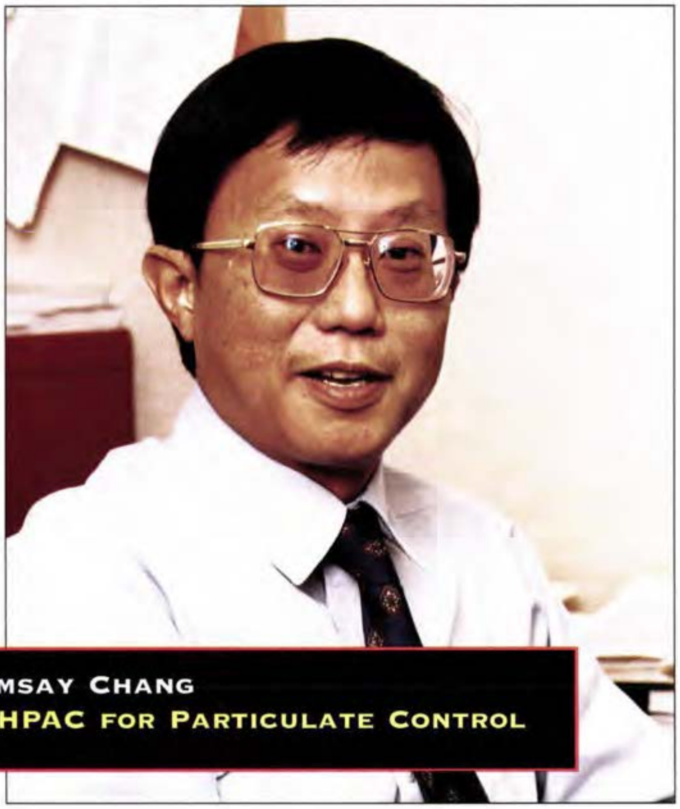
GIL ADDIS
TERRASIGHT SPILL DETECTION INSTRUMENT

Cleaning up an oil or PCB spill can cost several hundred thousand dollars. Being able to delineate the extent of the spill quickly and minimize the amount of soil that must be removed can lower this cost significantly. Gil Addis led the development and commercialization of a device, called Terrasight, that can quickly outline the extent of soil contamination by shining an ultraviolet light on the spill and detecting the fluorescence of the fluids.

Addis identified the research area, managed the development of Terrasight, and helped bring the device to commercialization in 1992. Since commercialization, Terrasight has received both the R&D 100 Award and the Photonic Circle of Excellence Award. Several utilities have purchased the device for routine use in detecting spills and taking remedial action.

"A utility could save 20 times the price of the instrument per spill, particularly if the spill is large," Addis says. "Terrasight is so easy and quick to use that it's becoming the standard instrument in the field." ■

D E V E L O



RAMSAY CHANG
COHPAC FOR PARTICULATE CONTROL

ARUN MEHTA

The performance of a significant number of electrostatic precipitators (ESPs) on U.S. utility power plants will have to be upgraded because of equipment aging, the impact of the Clean Air Act Amendments of 1990, and the emergence of more-stringent air emissions regulations. The Compact Hybrid Particulate Collector (COHPAC), which is currently arousing wide utility interest, has the potential to save the industry well over $1 billion in capital costs compared with other ESP upgrade options.

Ramsay Chang invented COHPAC by combining principles of electrostatics and barrier filtration physics. He patented the concept for EPRI, brought it through demonstration on a 150-MW power plant, and then found two licensees (two other licensing arrangements are pending) to commercialize the technology. His personal involvement and leadership at each stage of the product cycle were instrumental in moving COHPAC from conception to commercialization in an unusually short time.

"Several utilities are evaluating COHPAC at pilot scale, and one order has been placed for an 1100-MW station," Chang says. "EPRI is now looking at potential improvements, such as integrating the precipitator and baghouse into one unit and extending COHPAC capabilities to include the capture of other pollutants, such as air toxics." ■

The Coal Quality Impact Model (CQIM) is software that helps users evaluate the impacts of coal properties on power plant performance. Applications include predictive maintenance and maintenance planning, evaluation of plant retrofit decisions, and analysis of fuel switching and blending options for performance improvement and Clean Air Act compliance.

Arun Mehta conceived CQIM and worked with a contractor to develop it; David O'Connor oversaw its delivery to utilities. (Although the CQIM work is described in this Development section, O'Connor was presented with a Delivery Award.) The software is now used worldwide and has been accepted as the de facto standard for coal effects analysis. A new mathematical

P M E N T

DAVID O'CONNOR **COAL QUALITY IMPACT MODEL**

HUI-TSUNG TANG
NUCLEAR SEISMIC DESIGN EXPERIMENT

modeling approach is used to provide detailed evaluations of the coal-pile-to-busbar costs associated with burning coals and lignites in all types of boilers with a variety of environmental controls.

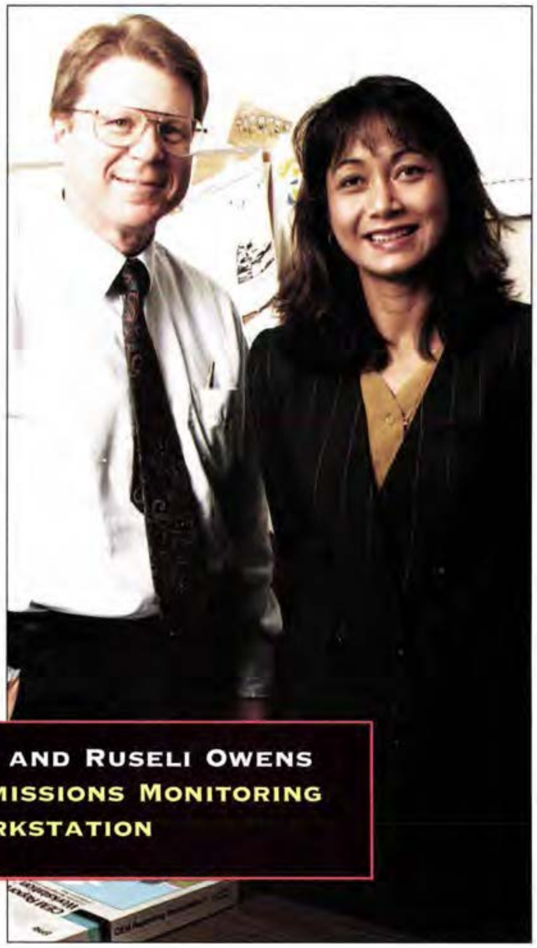
Continuing work seeks to extend the success of CQIM—for example, by using the model as a building block for other products with enhanced features. The development of one such product, called CQE, is the only software effort included for funding under the Department of Energy's Clean Coal Technology Program; that project is scheduled for completion in 1995. CQE, which integrates CQIM with other state-of-the-art software, will provide a common database for all aspects of power plant operation. ■

Optimizing the seismic design of nuclear power plants has been hampered by a lack of real-world data on ground and structure motion. To develop such information, Hui-Tsung Tang designed a field experiment for measuring seismic motions during actual earthquake incidents. Out of this work has come a validated, technically sound set of modeling guidelines for the seismic design and analysis of nuclear plant structures and components. The achievement has provided relief to utilities having to meet stringent regulatory seismic requalification requirements and has helped establish the Institute as a world leader in this field.

The experiment was conducted on a one-quarter-scale nuclear plant containment structure that was fully instrumented to measure motions at a seismically active site in Taiwan. More than 20 strong-motion earthquakes were recorded, resulting in a database that could be used to validate analytical models and procedures. Five utilities so far have used the technology to gain regulatory acceptance of seismic design requalification of their plants and have realized significant cost savings.

"We have recently completed facilities at a second strong-motion site in Taiwan, which has soil conditions more typical of nuclear plant sites," Tang says. "We have already recorded one magnitude-4 quake, and measurements will continue for five years. This international effort is fostering closer working relations between EPRI and participants from Taiwan, Japan, Korea, and France." ■

D E L I V E



CHARLES DENE AND RUSELI OWENS
CONTINUOUS EMISSIONS MONITORING REPORTING WORKSTATION

Several billion dollars worth of continuous emissions monitoring (CEM) equipment has been rushed into service with no provision for managing the more than 600,000 data points per unit that by law must be reported to the Environmental Protection Agency annually. The CEM Reporting Workstation, developed and delivered by Ruseli Owens and Charles Dene, is a corporate data management system that a utility can use to prepare emissions data in an acceptable format for the EPA and to provide data for its own use in optimizing compliance strategies.

Through the strong personal involvement of Owens and Dene, the workstation software was prepared and delivered in less than a year—a dramatic cut in normal product cycle time. At least 50 copies of the workstation, which is available through the Electric Power Software Center, are already in use by utilities, and a users group has been formed to provide support and guidance for future product enhancement.

In addition to reducing the cost of managing emissions data, the CEM Reporting Workstation can enable utilities to realize savings in fuel purchases and dispatch through closer tracking of emissions. For example, one utility expects to reduce fuel costs by about 5% by using the workstation to maximize its use of cheaper fuel. ■

In the middle of 1992, the Edison Electric Institute (EEI) contacted Ishwar Murarka for assistance in gathering scientific information to present in support of a lawsuit over whether utility coal combustion wastes were hazardous. The Environmental Protection Agency was under court order to make a decision quickly about whether further studies were needed on the issue. EPRI information compiled by Murarka constituted about 75% of the submissions from all sources.

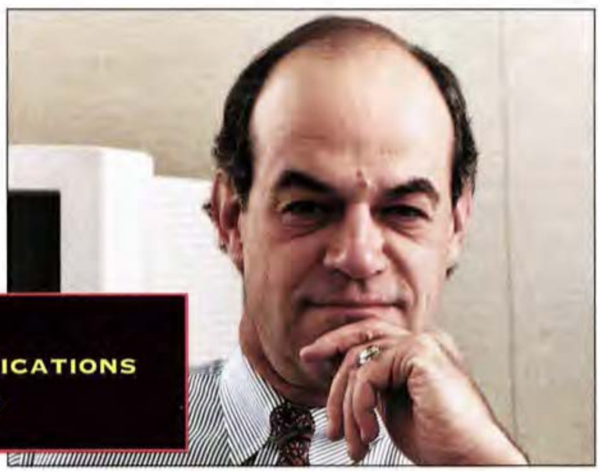
On the basis of these submissions and its own independent collection of information, the EPA decided that adequate information was available and made a regulatory determination that high-volume utility wastes are nonhazardous. EEI estimates that the resulting avoided costs to the industry for the handling and disposal of the wastes amount to about $1 billion to $2 billion annually.

"The remaining issue we are addressing is the comanagement of high-volume and low-volume utility wastes," says Murarka. "A regulatory determination will be made by April 1998, so we will be developing information and assessments pertaining to the issue during the next four years, with particular emphasis on coal-milling rejects—that is, pyrites." ■

R Y

LARRY E. LEWIS
CUSTOMER ASSISTANCE CENTER

ISHWAR MURARKA
COAL COMBUSTION WASTE CLASSIFICATION



ROBERT JEFFRESS
EPRIAMP COMMUNICATIONS SUPPORT NETWORK

To enhance technology transfer, Robert Jeffress formed the EPRIAMP Communications Support Network, which is designed to provide centralized access for member utilities seeking information and services from more than a dozen Customer Systems Division technology centers. In addition, EPRIAMP offers a members-only hotline, monthly briefings, customized mailings, and on-site staff visits to ensure that members' needs are fully met. In 1992 EPRIAMP handled more than 4000 inquiries and expanded its outreach mailings to nearly 2000 utility marketing representatives.

Jeffress originally created EPRIAMP (at first called AMP) to serve the Customer Systems Division's Industrial Program, but it proved so effective that the service has now been enlarged to cover the whole division. Since its formation, EPRIAMP has significantly improved utility awareness of the division's products and has been highly rated by member utilities as a way to gain easier access to a complex menu of services.

"In 1994 we'll be expanding utility awareness that EPRIAMP now covers the entire division," Jeffress says. "This increased coverage will support utility professionals working in all end-use markets." ■

When the Customer Systems Division was looking for a better way to increase member utilities' use of its energy end-use products, Larry Lewis worked to create the Customer Assistance Center. The goal in developing CAC was to provide a quick and easy one-stop resource to help members select from among the division's demand-side and end-use research and products and to facilitate technology transfer. Over the past three years, CAC has provided support to 280 utilities through 7200 hotline calls, conducted 105 on-site jump starts, and trained more than 6000 member utility staff.

Lewis was involved in the establishment of CAC at every step of the way. He outlined the operational approach for the center, pioneering such services as jump starts, deposit accounts, RemoteLink, and the hotline. In order to ensure the center's operational success, he moved to Dallas in 1990 and established EPRI's Dallas regional office. In a relatively short period of time, CAC has become nationally known for its responsiveness to member needs. As a result of its success with members (it was given an "Exceeds expectations" rating by more than 90% of CAC users), several other EPRI divisions have established similar assistance operations.

"Breaking new ground is always a challenge, but the satisfaction of helping hundreds of members learn about and apply our products has been well worth the effort," says Lewis. "It's particularly exciting to spearhead the concept of real-time delivery—or, as I call it, just-in-time transfer of EPRI R&D." ■

Living With Lightning

by Leslie Lamarre

In a twentieth-century spin-off from Benjamin Franklin's famous kite experiment, EPRI-sponsored researchers are developing a laser-based technology that could provide a way to guide lightning bolts safely to the ground. If successful, the technique could be used to protect sensitive utility equipment, improve customer service, and save lives.

Lightning kills several hundred people annually and causes millions of dollars in damage to structures that stand in its way. Among the vulnerable structures are utility power systems. During an average year in the United States alone, thunderbolts cause more than $100 million in damage to power lines, transformers, and other utility equipment. That is not surprising, since on average more than two lightning strikes occur every second of the year in this country. Even more significant is the consequential loss in customer productivity. A lightning strike resulting in two days of downtime at a manufacturing plant employing 200 workers would cost $320,000 in labor alone.

"Not only is lightning destructive, but it is one of the major causes of power quality and reliability problems in susceptible areas," says Ralph Bernstein, who manages EPRI's lightning research. For example, one utility in Florida, which is an active lightning region, reports that lightning is responsible for roughly 40% of its outages, faults, and breaker trips.

Technological advances over the past decade have improved matters somewhat. EPRI researchers have developed a national system for lightning detection that utilities can rely on to better predict and prepare for lightning storms. (See the sidebar for more details on that system.) The Institute has also developed the Lightning Protection Design Workstation, a sophisticated software program that helps transmission and distribution system experts design systems with a specified degree of protection. And in a separate effort—in which EPRI-sponsored researchers are launching small rockets into thunderclouds to trigger and direct lightning strikes—valuable new information has become available about the impact of lightning on utility systems, including such

Photo by Peter Menzel

THE STORY IN BRIEF As many as 100 lightning flashes occur around the world each second. Electric utilities know well the impact of lightning in terms of dollars, lost productivity, and lives. EPRI research, which began with a study of lightning's natural characteristics, has resulted in tools utilities can use to better track and prepare for thunderstorms. Recently the Institute completed a series of tests using small rockets to trigger and direct lightning strikes. Now EPRI-sponsored researchers are developing a laser-based technology they believe will be able to guide thunderbolts safely to the ground and ultimately even to discharge thunderclouds.

equipment as underground distribution cables.

But perhaps most fascinating and difficult of all, EPRI-sponsored research is currently under way at the University of New Mexico to develop a laser-based system that, if successful, will guide thunderbolts safely to the ground. Jean-Claude Diels, the professor of physics and electrical engineering who is conducting the research, expects that the technology will ultimately be capable of discharging thunderclouds of their lightning. Diels envisions this technology in continuous operation around the country—at utility plants, airports, rocket launch sites, and other lightning-sensitive locations. "You could even put these things on golf courses," says Diels.

A natural spectacle

Lightning's natural spectacle has fascinated humankind for millennia, and it's no wonder. The voltage of a single bolt ranges from 100 million to 1 billion volts, and its peak temperature is 10 times hotter than the surface of the sun. Most of lightning's energy is used to generate thunder, heat, light, and radio waves, leaving only a small fraction of energy in the lightning channel.

It wasn't until the era of Franklin's famous kite experiment some 240 years ago that lightning was proved to be an electrical phenomenon. During a storm, the base of a thundercloud picks up extra electrons, giving it a negative charge. The ground, meanwhile, has a positive charge. When the cloud's electric field increases to a sufficiently high level, the excess electrons leap from cloud to ground in a violent spark. (Sometimes the situation is reversed—that is, the cloud base has a positive charge and the ground a negative charge.)

A complete lightning discharge, called a flash, typically lasts a few tenths of a second. Although we perceive a lightning flash as a single stroke (and occasionally it is), most often a flash is composed of a number of individual strokes—typically three or four—separated by thousandths of a second. As many as 20 strokes have been recorded in a single flash. The multiple strokes in a flash make lightning appear to flicker. Special photographic techniques can record individual strokes within a single flash and have enabled scientists to study this phenomenon.

HOW IT HAPPENS Typically starting in the base of a cloud, lightning most often travels from cloud to ground. Initiating the discharge is an invisible traveling spark called a stepped leader. Just before the stepped leader makes contact with the ground, a spark travels upward from the point that is to be struck and meets the stepped leader. At this time, the visible flash occurs, following the path cut by the stepped leader and the traveling spark. Tall structures like transmission towers are particularly vulnerable to lightning strikes.

The multiple-stroke characteristic of lightning can be particularly harmful to electrical systems. Although lightning arresters are designed to withstand multiple lightning strokes, many successive strokes can stretch them beyond their ratings and either destroy or deteriorate them to the point that they are more susceptible to future damage. EPRI-sponsored researchers at the State University of New York at Albany are currently investigating the multiple-stroke phenomenon in more detail.

Most lightning begins in the base of a cloud and travels toward the ground. Initiating the discharge is a phenomenon called the stepped leader, a traveling spark invisible to the human eye. This spark cuts a jagged, stepped trail to the ground and is followed by the visible lightning flash. Just before the stepped leader makes contact with the ground, a spark travels upward from the point that is to be struck and meets the stepped leader, completing the connection between the ground and the cloud. This is not the typical course for lightning that strikes tall structures, such as buildings, however. In most of these cases, the cloud-to-ground movement appears to occur in reverse, with a stepped leader emanating from the top of the tall structure and traveling upward, toward the cloud.

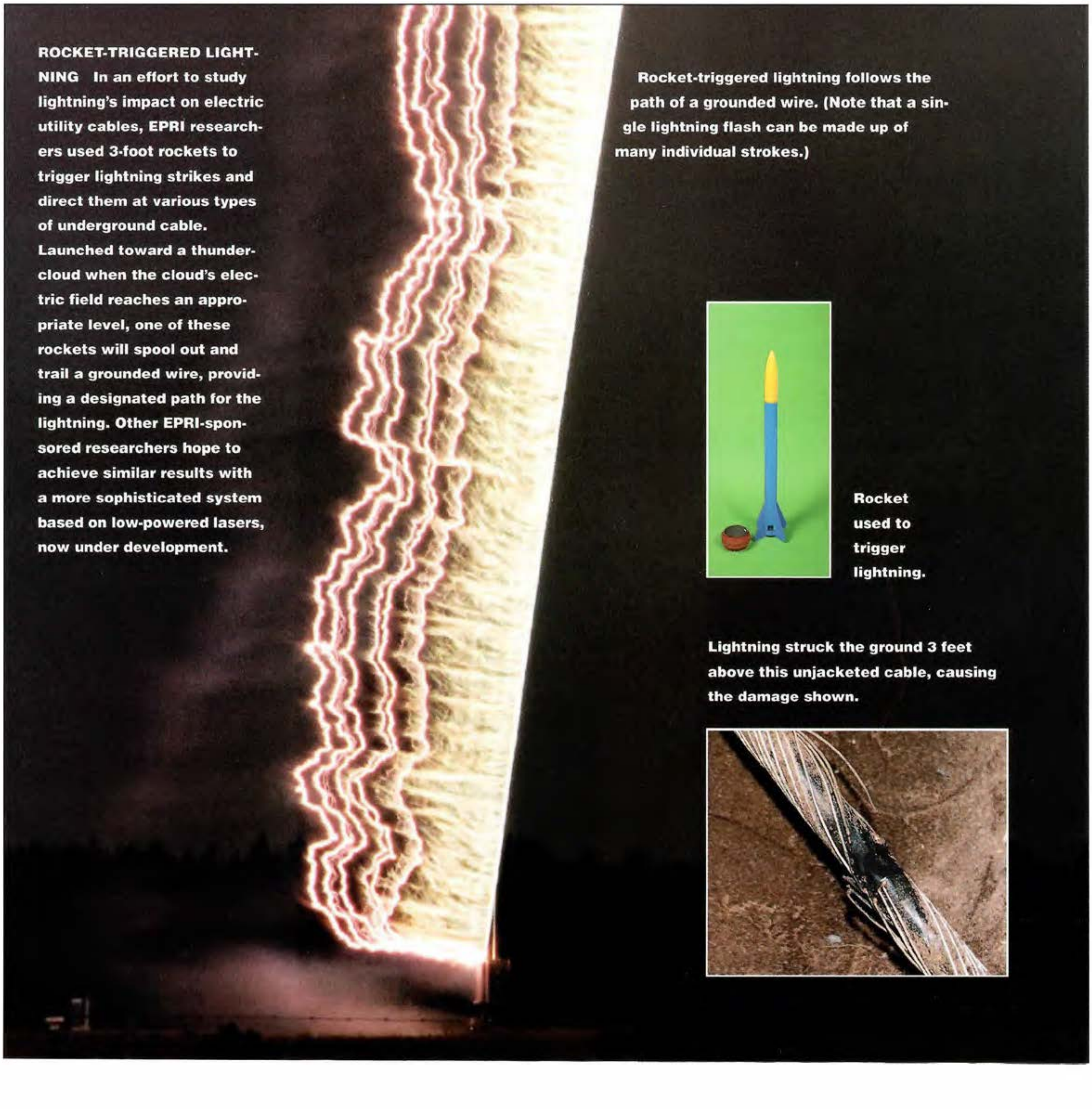
Martin Uman, a lightning expert with the University of Florida at Gainesville, says that the upward-traveling leaders could actually be oversized sparks traveling upward, separated by a significant distance from their downward-moving stepped leaders. These upward-traveling sparks may come into contact with the downward-moving leaders at cloud level, or they may simply end in the cloud region. "The two biggest remaining mysteries about lightning are how it gets started in the cloud and exactly how it attaches to the ground," says Uman.

Rocket science

Like Franklin's kite, tall objects such as buildings can function as lightning rods, providing a conduit that guides the electric energy of thunderbolts to the ground. The rockets employed by EPRI researchers play a similar role and are actually used to trigger lightning strikes. Launched toward a thundercloud when the cloud's electric field value reaches approximately −5.5 kilovolts per meter, the 3-foot rockets spool out and trail a grounded wire that provides a designated path for the lightning strikes.

The intent of EPRI's work with these rockets is to take advantage of this ability to direct lightning strikes so that researchers can study the impact of lightning on utility equipment. Once the wire is attached to the appropriate ground, the rocket is launched. As the rocket climbs, the electric field at its tip increases significantly. This is due to the charge flowing up the wire. The field continues to increase until lightning is triggered. The first stroke travels down the wire to the ground, actually melting the wire along the way and creating an ionized gas channel. Subsequent strokes follow the ionized channel.

Last summer, EPRI used the rocket-triggered lightning technique in field tests at a specially equipped testing facility located in an active lightning region about 25 miles southwest of Jacksonville, Florida. In three months of testing, researchers fired 50 rockets, triggering 32 lightning strikes. The primary aim of this study was to assess the impact of lightning strikes on



ROCKET-TRIGGERED LIGHTNING **In an effort to study lightning's impact on electric utility cables, EPRI researchers used 3-foot rockets to trigger lightning strikes and direct them at various types of underground cable. Launched toward a thundercloud when the cloud's electric field reaches an appropriate level, one of these rockets will spool out and trail a grounded wire, providing a designated path for the lightning. Other EPRI-sponsored researchers hope to achieve similar results with a more sophisticated system based on low-powered lasers, now under development.**

Rocket-triggered lightning follows the path of a grounded wire. (Note that a single lightning flash can be made up of many individual strokes.)

Rocket used to trigger lightning.

Lightning struck the ground 3 feet above this unjacketed cable, causing the damage shown.

SOME FACTS ABOUT LIGHTNING

- **Benjamin Franklin's famous experiment of 1752 was not the first to prove that lightning is an electrical phenomenon. Just a month or so earlier in France, Thomas-François d'Alibard proved it in another experiment devised by Franklin.**

- **The peak temperature of a typical lightning bolt is about 10 times hotter than the surface of the sun.**

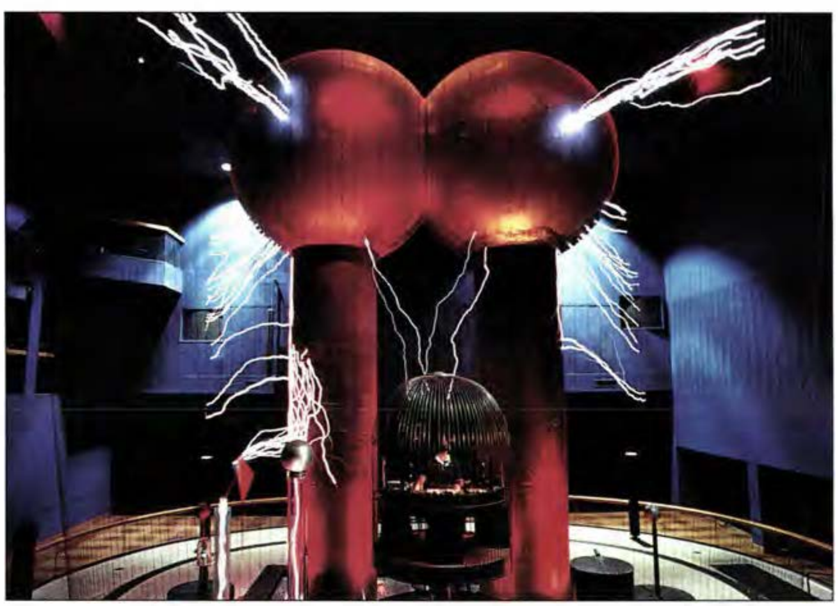
- **Although lightning almost always strikes the tallest structure in its path, it occasionally does not.**

- **Commercial airplanes are struck by lightning once every 5000 to 10,000 hours of flying time, on average.**

- **Lightning-strike victims who have stopped breathing and have no heartbeat can often be fully revived.**

- **The Empire State Building is struck by lightning an average of 23 times a year.**

- **Florida—specifically the Tampa area—is the most active lightning region in the United States, averaging as many as nine flashes per square kilometer annually.**



Simulated lightning travels the path created by the frame of this cage at the Boston Museum of Science, leaving the person inside unharmed. (Photo by Peter Menzel)

underground utility cables.

The results available so far show that lightning strikes to the ground 3 feet above a buried unjacketed cable caused significant damage to the concentric neutral wires wrapped around the cable. Currents from strokes traveling along the neutral wires measured over 5000 amperes. "We expected to see high currents, but we did not anticipate that level of damage," says Bernstein. Voltages measured in the insulation between the center conductor and the neutral wires were low, typically less than 10 kilovolts.

Another interesting finding from the rocket-triggered lightning tests is that a lightning strike to the ground above a primary cable resulted in a 3-kilovolt surge on a secondary electrical system roughly 100 yards away. That surge—strong enough to cause damage to electric appliances—was significantly higher than expected, indicating the potential need for additional protection on secondary systems.

Two types of jacketed cable, one using semiconducting material and the other insulating material, also were tested. The jacketed cables were installed underground in two ways, buried directly in the earth and buried inside plastic piping. Those cables have not yet been excavated.

Final results from all the rocket-triggered lightning tests are expected to be available by the middle of the year. "Our goal is to determine whether we need new cable designs or other protection methods," Bernstein says.

The laser approach

The research under way at the University of New Mexico aims to go one step further with the triggered-lightning concept, attempting to control the flashes not just for testing purposes but also for equipment protection and human safety. To accomplish this, EPRI-contracted researcher Jean-Claude Diels and research associate Xin Miao Zhao of the university's Department of Physics and Astronomy are developing a system based on low-powered lasers.

Theoretically, Diels says, such a system would work by means of two laser beams: one with a short, ultraviolet (UV) wave-

TRACKING LIGHTNING NATIONWIDE

One of the most valuable tools for helping utilities plan for thunderstorms is the National Lightning Detection Network™. Developed by the State University of New York under contract to EPRI and now operated by GeoMet Data Services (a subsidiary of Dynatech Corporation), the NLDN allows users to track, in real time, information on lightning activity in their regions.

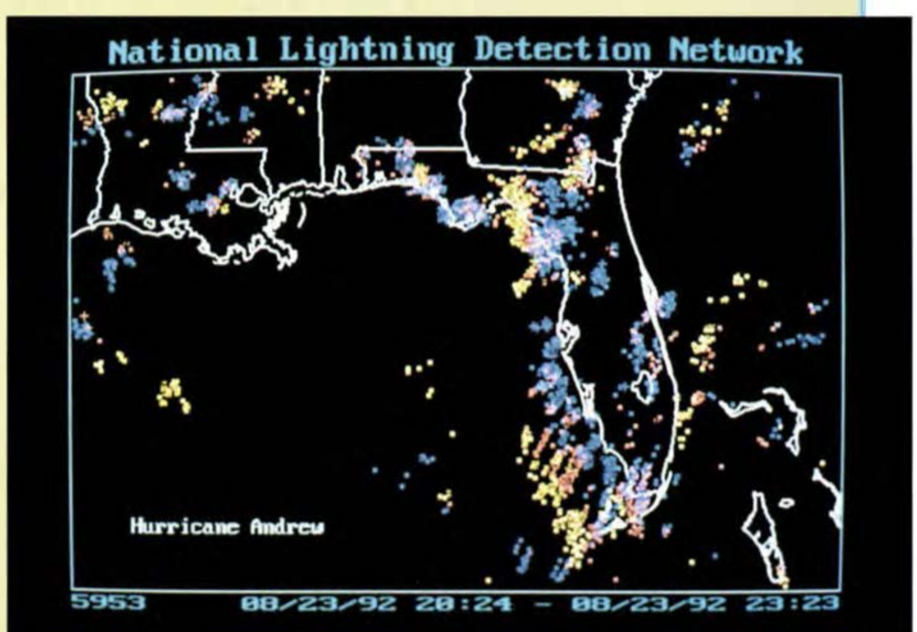
The NLDN is a computer-based system that displays the location, time, and severity of lightning strikes as well as the movement of thunderstorms across the United States. These data are gathered through more than 130 remote field sensors that detect and monitor lightning strikes. Satellites relay the sensor information to communications satellites, which send the data to the network's control center in Tucson, Arizona, for processing. The control center computes the lightning's characteristics and location. Users receive the data within seconds of the real-time activity. Displayed on a map of the United States through an IBM or IBM-compatible personal computer, the information can be easily interpreted.

The EPRI-sponsored project to develop the NLDN began in 1984. Today more than 100 users subscribe to the network. Although the bulk of those who use and benefit from the NLDN are electric utilities, there are also subscribers from a variety of other industries, including forestry, telecommunications, and commercial airlines. The users report numerous practical benefits: commercial airlines have been able to avoid unnecessary delays, service companies like Federal Express have used the system to help ensure the safety of their employees, and electric utilities have reported significant time and money savings by using the network to react faster to outages and to avoid the unnecessary deployment of storm-watch crews. In fact, the experience of individual EPRI member utilities indicates that the value of the efficient dispatch of repair crews alone ranges from tens of thousands to several hundreds of thousands of dollars in annual savings.

The network also has educational benefits. Universities and research organizations, including the National Aeronautics and Space Administration and the National Oceanographic and Atmospheric Administration, are using the NLDN to help improve our understanding of storm and lightning phenomena.

The NLDN's control center in Tucson, Arizona.

An NLDN subscriber's computer screen shows lightning activity during Hurricane Andrew in 1992.



length and one with a longer, green wavelength. The two beams would be directed toward a thundercloud in close sequence, with the UV laser beam preceding the green one by less than a nanosecond. The UV laser beam would create a slightly conductive path between the cloud and the ground—a plasma channel of electrons and ions. The electrons generated by the UV beam would multiply to the point that they would induce an electric discharge—a lightning flash. The green beam would help maintain the conductivity of the plasma path and guide the thunderbolt to the ground along that path.

Diels is confident that this technique can be used to divert lightning away from people and sensitive equipment, saving lives and money. So far in the laboratory he has managed to induce a 0.25-meter-long lightning bolt in an electric field of half the intensity required for lightning to occur naturally. He says that by using focused lasers it is theoretically possible to trigger lightning in an electric field measuring only one-tenth of the natural intensity.

Diels triggered the artificial lightning in the laboratory by directing a UV laser beam 100 micrometers in diameter through two aligned electrodes. As would happen between ground and cloud, the electric fields at both tips of the plasma conduit created by the laser increase so significantly that the molecules at both ends become ionized. The ionized region moves at one-third the speed of light, and a lightning flash occurs. Diels notes that tests involving simulated lightning flashes traveling much greater distances would require large power supplies (about 400 million volts for a 100-meter flash), which are generally unavailable in a laboratory.

Diels says that it took only 200 microjoules of pulsed laser energy to induce the 0.25-meter lightning bolt. A flash of 300 meters, a typical distance between cloud and ground, would require some 20 millijoules. The laser beams expected to be used in the field will be conical in shape: the diameter will measure 30 centimeters to 1 meter at the ground, focusing down to less than 1 millimeter near the thundercloud. Diels, who has been under contract to EPRI since May 1993, continues work that will define the precise level of laser power required for the full-scale system. He has already obtained a patent on the technology. Fieldwork is expected to start late in 1995.

"The development of this laser technology is a logical next step in the course of EPRI's lightning research," says Bernstein. "We started out studying lightning's natural characteristics. The use of rockets to trigger lightning then allowed us to study lightning's potential impact on utility systems. Our hope is that our current work on the laser-based system will provide us with a far more sophisticated method for inducing lightning. Our ultimate goal is to use the laser technology to mitigate lightning in susceptible areas."

Other approaches

EPRI is not the only organization working to develop a laser-based technique that will induce lightning. Scientists in Japan are experimenting with high-powered infrared lasers to perform a similar function. Inspired by a lightning strike last February that triggered the automatic shutdown of a 460-megawatt nuclear reactor, the researchers are now testing the feasibility of using a 300-megawatt laser as a lightning rod. So far they have managed to guide an artificial lightning bolt a distance of 8.5 meters.

Bernstein believes that the low-powered laser technique being developed by Diels offers several advantages over the high-powered infrared laser technique. One fundamental difference is the capability of the UV laser to provide a steady conduit after a lightning flash, enabling the flash to be safely guided to the ground. By contrast, the beam generated by an infrared laser is opaque to lightning flashes, requiring extensive manipulation to accomplish the same task. "The use of low-powered laser beams permits a safer, more controllable, and more technologically sophisticated process," Bernstein says.

The low-powered laser approach also offers advantages over the rocket-based technique for triggering and directing lightning, says Bernstein. The laser approach is expected to achieve a higher level of accuracy than the rocket technique, which works only about 60% of the time. Another potential advantage of the laser technique is that it could be operated continuously, unlike the rocket technique. Also, lasers could be used to sweep the sky above a sensitive facility. These last two advantages, says Diels, give the laser technique the potential to be used to discharge thunderclouds over a certain area continuously, effectively preventing lightning from harming equipment and people in the area. By contrast, a rocket can set off only one lightning strike. Triggering multiple flashes in a single storm with the rocket technique would require significant resources.

The laser-based technique does raise some issues that need to be addressed. One concern is the potential for damage to the mirror device that is expected to be used to direct the laser energy into the sky. Also, many parameters are needed for the system design, and the development of those parameters will require extensive field tests. The anticipated high cost of the laser system is another concern.

Some lightning experts, like Uman, are skeptical about the potential for laser-based technology to discharge thunderclouds. "At this point, we don't know whether the rocket technique triggers lightning that would have occurred naturally or whether it is initiating flashes that never would have occurred," Uman says.

Bernstein agrees that there are many problems to overcome and that the project has a significant risk of failure. Still, he says, the laser concept is worthy of research, and the potential rewards are too significant to ignore. "Developing this technology will be a difficult task," Bernstein says. "There are high technological risks and uncertainties. But if we are successful, the returns—not just in dollars but in lives saved—could be very, very high." ■

Background information for this article was provided by Ralph Bernstein, Electrical Systems Division.

CONTRIBUTORS

Technical sources for Journal feature articles

CHOW

TORRENS

HUGHES

BERNSTEIN

Hazardous Air Pollutants: Measuring in Micrograms (page 6) was written by Taylor Moore, *Journal* senior feature writer, with principal guidance from two members of EPRI's Environment Division.

Winston Chow heads EPRI's Waste & Water Management Program. Before joining EPRI in 1979, Chow worked for Bechtel Power Corporation for seven years as a power plant design engineering supervisor. Earlier he worked for Raychem Corporation on polymer research and development. Chow earned a BS degree in chemical engineering from the University of California at Berkeley, an MS in the same subject from San Jose State University, and an MBA from San Francisco State University.

Ian Torrens has directed the Environmental Control Systems Department, which includes the Waste & Water Management Program, since he joined the Institute in 1987. He was formerly with the Organization for Economic Cooperation and Development for 14 years, including 7 years in the Environment Directorate as head of the Pollution Control Division. Before that, he was a researcher with the French Atomic Energy Commission. He received a BS degree in physics from Queen's University (Ireland) and a PhD in physics from Cambridge University (England). ■

Electricity From Whole Trees (page 16) was written by Leslie Lamarre, *Journal* senior feature writer, with background information from Evan **Hughes**, manager for renewable fuels in the Generation & Storage Division. Hughes joined EPRI in 1978 after serving as manager of the Geothermal Energy Office of the California State Energy Commission. Before that, he was a senior member of the technical staff at SRI International, specializing in the analysis of energy, resources, and the environment. Earlier he was a physics professor at Pomona College. Hughes has BS, MS, and PhD degrees in physics from the California Institute of Technology. ■

Living With Lightning (page 32) was written by Leslie Lamarre, *Journal* senior feature writer, with assistance from **Ralph Bernstein**, manager of lightning research and development in the Electrical Systems Division's Custom Power Distribution Program. Bernstein came to EPRI in 1992 after 13 years with the IBM Palo Alto Scientific Center. There, as a senior technical staff member, he was responsible for geoscientific and medical image processing R&D. Before that, he worked with the IBM Federal Systems Division in Gaithersburg, Maryland. Bernstein received a BS degree in electrical engineering from the University of Connecticut and an MS in the same subject from Syracuse University. ■

Board Adopts New Business and Membership Strategy for EPRI

Concurring with the Institute's proposed strategy to better serve the needs of an evolving electric power industry, the Board of Directors adopted a series of sweeping changes in EPRI's business plans and membership policies at its December meeting in Dallas. Of the several separate but related measures, the most far-reaching will provide member utilities significantly more flexibility in both the amount and the allocation of their payments for a redeployed research, development, and delivery (RD&D) program.

Other changes approved by the Board include amendments to EPRI's bylaws to create a new membership class for affiliated power producers (APPs) and independent power producers (IPPs), extension of the Tailored Collaboration (TC) supplemental funding program to include international affiliates of EPRI, and adoption of a streamlined RD&D planning and authorization process.

Progressive Flexibility

With the Board of Directors' approval, EPRI's business strategy is now geared toward the implementation, beginning in 1995, of a new membership offering termed Progressive Flexibility. In return for a multiyear commitment to EPRI funding, members will gain increased flexibility of choice from a menu of research programs in the RD&D plan. EPRI will also continue to offer the single-package annual membership option to those members and industry segments who prefer that traditional arrangement. In all cases, a maximum of 40% of a member's dues will be allocated to the core RD&D program, which will consist of research in areas of vital interest to all members, plus key exploratory research efforts.

Members making a two-year commitment under either of two Progressive Flexibility options will be able to allocate a portion of their funding among 10–15 business units organized around specific areas of current EPRI-supported research. The program content of the core and the elective business units will be more precisely defined through a new target authorization (TA) RD&D planning process. Launched early this year, the TA process will translate the technology needs of the industry into interrelated results that EPRI will deliver. Business unit definitions are expected to be completed no later than March for use in membership solicitations for 1995.

Solicitations for EPRI membership under the new approach will be mailed in May, with responses to be received by July. Initially, flexible-funding membership options will be offered for a trial period of 1995 and 1996. A revised membership strategy, incorporating lessons learned during this trial period, will be developed for 1997 and beyond.

Members can elect to fund EPRI at the 100% dues level (that is, at the same level as current dues), and those that do will have access to all EPRI results, regardless of business unit funding allocations. But members that elect to fund at between 80% and 100% will have access to EPRI information from only the core and those business units they choose to fund at or above a minimum level established for each unit.

Details of the Progressive Flexibility business strategy were endorsed by EPRI's Research Advisory Committee (RAC) in November. RAC chairman Bill Boston, president and CEO of Wisconsin Electric Power Company, joined EPRI management in presenting the final proposals to the Board of Directors. EPRI's new business strategy is likely to require changes in its industry advisory structure; options for those changes will be developed for discussion with RAC and review by the Board, and a decision will be made in April.

Definitions of the core and the elective business units, and subsequent funding decisions, may necessitate a realignment of EPRI business systems, management, and staffing. An EPRI transition team has been created to translate the business strategy into implementation guidelines for EPRI's members and staff. The realignment process will begin in the second quarter of 1994 and is likely to continue into 1995 or later.

Tailored Collaboration expanded

Through 1995, TC supplemental funding—investment over and above basic dues that allows members to target specific projects and have a matching amount of their EPRI dues allocated to those efforts—will continue to be allowed in amounts of up to 25% of a member's dues. But during 1995 the compatibility of TC with Progressive Flexibility will be evaluated, and a recommendation will be made regarding the appropriate level of TC funding for 1996 and beyond. Under the flexible membership options, TC funding will be allowed only for the core and for the business units in which a member is participating.

The Board also approved extending the TC funding option to the five international affiliates (three in Europe, one in Canada, and one in Australia) that have already made three-year commitments to specific strategic targets in the EPRI RD&D plan. TC was not previously an option for affiliates, who pay annual fees based on the same formula that applies to EPRI members (plus a premium), prorated to the relative budgets of the strategic areas to which the affiliates are committed. Now, up to 25% of an international affiliate's fees may be targeted, along with its additional matching TC funds, to projects within the areas of affiliation.

In addition to the potential for attracting nearly $3 million in additional research funds, extending the TC option to affiliates is expected to add value for domestic EPRI members through expanded access to international RD&D results and experience, help attract and retain non-U.S. utilities with important RD&D programs, and help preserve and expand the basic collaborative nature of EPRI's program.

New membership class

Expanding the membership ranks to represent the entire electric power industry and broadening the base of future support for the EPRI program are the key reasons for a new membership class, which offers participation to nonregulated sellers and producers of electricity.

The new class, sanctioned by the Board of Directors through amendments to the Institute's bylaws, extends to APPs and IPPs the full privileges of membership, including access to EPRI research results and the right to elect a new member of the Board of Directors. The change, effective January 1, 1994, was recommended to the Board and to its Membership and Strategic Issues Subcommittee in August 1993 by EPRI's management. Factors cited in support of the move include the changing structure of the industry, the need to broaden EPRI's base of future financial support, and further assurance that membership be available to all industry participants on a nondiscriminatory basis.

The bylaw amendments provide for a dues formula for the new member class comparable to that for existing members (i.e., 0.33% of gross electricity revenue). New members will be eligible to participate in EPRI's industry advisory structure to the same extent as existing members, in accordance with revisions that may be forthcoming under the Progressive Flexibility strategy. In addition to a dedicated seat on the Board of Directors, the new member class has the same right as other member classes to a second seat on a rotating basis. The amendments to the bylaws increased the total number of EPRI Directors to 26 to allow for the additional seat.

Target authorization process

The new TA process proposed by EPRI senior management and then approved by the Board of Directors in December is expected to shift the EPRI-industry dialogue from its historical focus on monitoring EPRI research to defining the highest-value results in consultation with members. The new process, which began in January 1994, streamlines the authorization of EPRI research activities and expenditures and elevates authorization activity from the current project level to the strategic target level.

Each target is a discrete building block in the EPRI program, representing scientific and technical results that satisfy an explicit member need. The TA process will provide a more focused mechanism for ensuring EPRI accountability for results agreed upon for each target. Individual TA documents for EPRI's RD&D plan, identifying the specific needs to be addressed and the expected EPRI responses, are to be developed this year in conjunction with member utilities. The documents, which are intended to serve EPRI and its members much like business plans, will include definitions of specific results to be achieved, their development and delivery schedule, and their associated costs. Business and management plans for the various results will be included as supplements.

EPRI's RAC, division committees, and task forces have reviewed and endorsed the TA process and participated in the development of guidelines for the preparation of TA documents. Industry advisory meetings in January were expected to reach a consensus on what the specific targets should be. RAC recognized that the implementation of Progressive Flexibility in 1995 could affect the TA process as it relates to the advisory structure and recommended that the TA guidelines be adjusted as necessary to reflect any such changes.

At advisory body meetings this May, the negotiated industry needs—along with the products and associated revenues necessary to respond to the needs—will be confirmed. The products that advisors and EPRI agree are the best for meeting each target's requirements will be prioritized. All TA documents are to be completed by the September 1994 advisory meetings, when they will be incorporated into EPRI's 1995-9 9 RD&D plan for approval by the Board of Directors. ■

Country's First EV Research Center Opens in Atlanta

Georgia Power Company played host to the news media, an enthusiastic public, and officials from a number of companies supporting the development of electric transportation, including EPRI, when it unveiled the country's first Electric Vehicle Research Center last fall. Housed at SciTrek, Atlanta's new museum of science and technology, the center includes an office of the Electric Vehicle Research Network (EVRN).

The center, which combines advanced research capabilities with educational displays, is the first of a series of utility-supported sites for electric vehicle (EV) evaluation and education under EPRI's EVRN project. The facilities are aimed both at helping to overcome EV technical limitations and at increasing public confidence in the technology's potential to improve air quality and reduce national dependence on imported oil. The Atlanta center will test and evaluate the latest EV technology, including various components of the infrastructure necessary to support the use of EVs.

The offices of the EPRI-coordinated EVRN will conduct customer education and research and share results. For EPRI they will provide a deployment mechanism for testing prototypes of residential and public charging systems. "By serving as infrastructure launch platforms and conducting closely related market-based research evaluation, the centers will give EPRI prompt feedback on charging-system preferences, human interface concerns, and overall customer perceptions of EVs," says Gary Purcell, a project manager in the Institute's Transportation Program.

The EVRN sites will have various combinations of EVs, depending on the purchases made by the participating utilities. The vehicles will include the Chrysler TEVan, the EPRI-developed G-Van, and the Ford Ecostar.

In addition to Georgia Power, these utilities are founding EVRN members, committed to establishing network offices: Alabama Power Company, Arizona Public Service Company, Boston Edison Company, Centerior Energy Corporation, Duke Power Company, New York State Electric & Gas Corporation, PECO Energy Company, the Salt River Project, the Tennessee Valley Authority, and Texas Utilities Company.

■ *For more information, contact Gary Purcell, (415) 855-2168.*

Rooftop Photovoltaic Test Effort Launched

EPRI and 11 member utilities have joined the Environmental Protection Agency (EPA) to install rooftop solar photovoltaic (PV) systems on 11 commercial and industrial buildings in a national test program. The $2.5 million collaborative effort will demonstrate the potential for emissions-free, distributed solar cell technology to improve air quality, reduce peak electricity demand, reduce energy costs for buildings, and lower the need for central-station generation and transmission capacity.

The PV systems are each rated at about 18 kW (ac) and have a combined installed capacity of about 200 kW (ac). They will be installed on office buildings and at universities, airports, and manufacturing facilities in Los Angeles, Boise, Denver, Las Vegas, Boston, and other locations early in 1994. Ascension Technology, Inc., of Waltham, Massachusetts, and the participating utilities will design and install the systems. Ascension, EPRI, and the EPA will monitor and assess the systems' technical, environmental, and economic impacts. This project is an expansion of an EPA-utility cost-sharing effort initiated in 1992 with 11 other utilities to examine PV systems in residential and some commercial applications.

12-kW system at Wisconsin Public Service Corporation

"The cooperative effort by the EPA, EPRI, and private industry will allow us to collect and evaluate a broad range of information for the utility industry on PV systems installed on buildings," says John Bigger, manager of photovoltaic system applications in EPRI's Solar Power Program. "We expect that the results of this demonstration will help utilities position themselves to apply PV technology in the near future."

Edward Kern, president of Ascension, notes that the long-range objective of the project is "to see the technology commercialized so that it becomes a standard option for rooftops in the future. The building sector could ultimately be a significant market for this technology across the United States."

The utilities that are committed to participating in the project are Arizona Electric Power Cooperative, Atlantic Electric, Boston Edison Company, Consolidated Edison Company of New York, Florida Power Corporation, Idaho Power Company, Los Angeles Department of Water & Power, Nevada Power Company, New York State Electric & Gas Corporation, Public Service Company of Colorado, and Public Service Company of Oklahoma.

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

Second Phase of Wind Turbine Verification Program to Begin

EPRI is broadening utility participation in a program intended to accelerate the adoption of advanced wind energy systems by U.S. utilities. Designed cooperatively by DOE and EPRI, the Utility Wind Turbine Performance Verification Program provides a bridge between today's development projects and the commercial purchase of utility-grade wind turbines by giving utilities an opportunity to gain firsthand experience with the latest in wind technology.

The joint program calls for DOE and EPRI to assist up to five host utilities in constructing, operating, and evaluating modern wind power plants—nominally 20 turbines per host. The installations will allow utilities to study costs, system integration issues, and environmental impacts.

Green Mountain Power Corporation and Central and South West Services are hosts for the first phase of the program. The Institute is now issuing a request for proposals for second-phase hosts in order to expand the number of turbine technologies and weather patterns covered in the evaluations.

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

Industrial Program

Electrotechnologies for Medical Waste Disposal

by Myron Jones, Customer Systems Division

Each year, U.S. health care facilities—including hospitals, laboratories, dentists' offices, and blood banks—produce approximately 466,000 tons of infectious waste (Figure 1). This waste, defined as being capable of spreading disease, includes a wide variety of materials, such as blood, "sharps" (e.g., syringes and scalpels), body parts, gloves, and tissue cultures. Traditionally, such waste was burned in dedicated incinerators, either on-site or at commercial facilities. New regulations on air emissions, however, have forced the closure of many incinerators and blocked the construction of new ones in many states. Tighter restrictions have also prevented landfills from accepting medical waste unless it has been disinfected and rendered unrecognizable. As a result, an aggressive search is under way to find new methods of treatment and disposal for this waste.

Several factors have contributed to the growing concern about infectious waste. First, improper handling, illegal dumping, and the subsequent appearance of medical waste in such places as beaches and dumpsters in a number of states have heightened public concern. Second, the spread of AIDS and hepatitis B has prompted many hospitals to consider all patient-contact waste as potentially infectious and has thus greatly increased the volume of medical waste requiring disposal. Finally, the high percentage of chlorinated plastics in medical waste has led to higher emissions of dioxin and furans from incinerators, making it more difficult for the incinerators to meet the provisions of the Clean Air Act Amendments of 1990. Some older incinerators also have had difficulty in handling the larger volume of hot-burning disposable plastics.

One regulatory action resulting from the concern about infectious waste was the passage of the Medical Waste Tracking Act of 1988. The act, whose most immediate impact was to require the Environmental Protection Agency to establish a two-year demonstration program for tracking infectious waste, is expected to serve as the basis for future regulations at both the federal and the state level. An earlier development was the publication (in 1986) of the *EPA Guide for Infectious Waste Management*, which established a standard of practice that has been duplicated extensively at the state level. Additional standards have been developed by the Centers for Disease Control, the Joint Commission on Accreditation of Health Care Organizations, and the Occupational Safety and Health Administration.

Seeking alternatives

Because of the economic and regulatory changes associated with the disposal of infectious waste, many health care facilities are seeking alternative waste disposal methods. Each alternative needs to fulfill two basic requirements: decontamination and disfigurement.

Decontamination involves rendering the waste biologically harmless. Usually the effectiveness of this process is measured by its ability to destroy or inactivate a designated heat-resistant pathogen placed in the waste. Disfigurement refers to changing the appearance of the waste to render it acceptable for ultimate disposal. In particular, sharps need to be melted or shredded beyond recognition. The disfigurement requirement resulted largely from the public outcry over the discovery of medical waste on beaches and at other public facilities, but it has had the added benefit of reducing the physical volume of waste requiring transport and disposal.

Electric utilities have an important stake in the search for medical waste treatment alternatives. Health care facilities are a valuable segment of the electricity market, and finding a satisfactory solution to the waste disposal problem is a factor in their viability. Also, many of the alternative technologies, in contrast to incinerators, are electricity based. By helping develop efficient, cost-effective electrotechnologies for treating infectious waste, utilities can help provide a cleaner environment and enhance their off-peak load while helping their customers in the health care industry remain competitive.

To encourage the development and commercialization of such electrotechnologies,

ABSTRACT *The disposal of infectious medical waste has become increasingly difficult, as tighter regulations have forced the closure of many hospital incinerators and as more and more landfills have refused to accept the waste unless it has been disinfected and rendered unrecognizable. Now, however, a variety of new, environmentally attractive electrotechnologies—involving pyrolysis, steam, microwave, and electron beam techniques—are becoming available to destroy or disinfect medical waste. EPRI is working with utilities and health care facilities to help bring these technologies into wider use.*

EPRI's Industrial Program has launched a collaborative project on medical waste disposal, with participation open to electric utilities and health care facilities. The project has sponsored a scoping study of medical waste management, a brochure on electrotechnologies for infectious waste disposal, and a series of technology data sheets and application case studies.

The project is also involved in demonstrations of several emerging disposal technologies. Project participants get early access to test data and reports, gain technical expertise on the technologies, and get preference for siting demonstrations. The project is also sponsoring economic evaluations of various treatment technologies and is developing software so that utilities can help their health care industry customers determine site-specific costs for each alternative.

The results of the scoping study, prepared by Doucet & Mainka, have been published in *Medical Waste Management: Regulatory and Technical Background Report* (EPRI TR-100978). The report describes the types of facilities that produce infectious waste, characterizes (on a national and a regional basis) the types and quantities of waste produced, reviews current and proposed regulations, characterizes the disposal needs of large and small waste producers, and describes current and emerging disposal technologies.

A preliminary study of the economic factors in medical waste disposal has been undertaken by the Wenatchi Group. The study includes the preparation of summary descriptions of various disposal technologies and the development of generic economic evaluations, including economic sensitivity analyses of variations on base case assumptions. The Wenatchi Group is developing these evaluations into software for both IBM and Macintosh computers; the software is undergoing beta testing and will be operational early this year.

The project is currently involved in evaluating or supporting demonstrations of the six technologies described below.

Plasma pyrolysis

Pyrolysis—or heating without oxidation—avoids the toxic emissions produced by incineration by using intense electric heat to break organic molecules down into a clean-burning gas. The glowing gas created in an arc by the passage of current is called a plasma. By blowing a steady stream of gas through an arc, a plasma torch is created, with temperatures many times hotter than those produced by ordinary combustion. The plasma pyrolysis process uses a plasma torch to gasify the organic material in medical waste while converting the metallic and siliceous fractions into an inert glassy slag. The product gas can be used on-site as a fuel; the slag is suitable for use as aggregate in road building or in other applications.

The first unit for demonstrating plasma pyrolysis for medical waste disposal is being installed at an 800-bed medical center in southern California. The system is scheduled for startup in late 1994 and is expected to operate off-peak for 8 hours a day, 7 days a week, at a rate of 1000 pounds per hour. It uses a plasma torch developed by Plasma Energy Corporation, a unit of the Mason & Hangar engineering firm.

Pyrolysis-oxidation

Many of the advantages of pyrolysis can be obtained with smaller units by combining, in the same equipment, the pyrolysis of organic materials and the oxidation of the resulting gases. Eshland Environmental Technologies of Greencastle, Pennsylvania, has developed a disposal unit, called the Bio-Oxidizer, that is based on this concept. Medical waste is loaded into the unit's pyrolysis chamber and is heated to temperatures of 200–600°F, which causes the organic materials to vaporize. These vapors are then drawn into a two-stage oxidation chamber operating at 1800–2000°F. The combined pyrolysis-oxidation reactions destroy all pathogens and reduce the waste volume by 95%, producing a solid, sterile residue. An integral heat exchanger recovers about 80% of the energy to produce hot water.

The Bio-Oxidizer comes in various sizes to meet the needs of facilities ranging from small clinics to large hospitals. Unit capacities range from 300 to 3000 pounds per day. The first commercial unit is in operation at a hospital in Chambersburg, Pennsylvania; other installations are planned for this year.

Figure 1 The infectious waste generated by U.S. health care facilities—about 466,000 tons a year—must be treated on-site or shipped to off-site treatment facilities. The volume of waste has grown rapidly because of an increased use of disposable materials and a broader definition of infectious waste. At the same time, several factors have made disposal more difficult, including new federal and state air regulations and the refusal of landfills to accept waste that has not been disinfected and rendered unrecognizable.

Microwave disinfection

An alternative to destroying medical waste is to render it harmless by microwave disinfection and shred it for disposal in municipal landfills. A system that meets these goals is currently being marketed by ABB Sanitec, which has installed commercial units at Forsyth Memorial Hospital in Winston-Salem, North Carolina; at Integrated Environmental Services, a regional medical waste facility in Oakland, California; and at more than 50 other locations in the United States. EPRI is following the performance of these installations on behalf of the participants in its medical waste disposal project.

The ABB Sanitec microwave unit shreds the waste, injects steam to provide moisture, and then disinfects the waste by exposing it for 25–30 minutes to heat (190–200°F) generated by microwave energy. Sharps are ground into small pieces. The volume of the resulting residue is about 30% of the original waste volume. The system comes in two unit sizes—one capable of treating some 550 pounds per hour, and the other, some 275 pounds per hour.

Steam sterilization

A steam sterilization process using an electric steam generator and multiple filters to control emissions has been developed by GTH Roland North America of Houston, Texas. In this process, shredded medical waste is exposed to steam at 311°F for a minimum of 20 minutes in a sterilization chamber. The decontaminated residue is then dried and ejected, while gases from the sterilization chamber are passed through a high-efficiency filter to remove particulates and an activated carbon filter to remove volatile organic compounds. Two models are commercially available: the ZDA-M3 system treats up to 900 pounds per hour; the SAS-1 unit handles 300 pounds per hour. Either model can be truck-mounted or assembled as a stationary plant.

Commercial versions of the ZDA-M3 have been installed at the Mayo Clinic in Rochester, Minnesota, and at Aegis Waste Management in Edmond, Oklahoma. Advantages of the GTH steam sterilization system include low energy requirements, 70–80% volume reduction, and quick startup. The technology has been used in Europe since 1986.

Steam reforming

A very different approach using steam has been developed by Synthetica Technologies of Richmond, California. In the Synthetica Steam Detoxifier, shredded waste is exposed to superheated steam at up to 1200°F, and the vapors produced are further heated to 3000°F in a detoxification reactor. The subsequent gas stream consists mainly of carbon dioxide and water. The solid residue consists largely of carbon in the form of graphite, plus varying amounts of metal and glass; its volume is approximately 2% of the original waste volume.

Treatment of medical waste by steam reforming has been demonstrated at a full-scale unit at Synthetica's Richmond facility, and the first hospital demonstration unit is under construction for a Georgia hospital. The Steam Detoxifier can treat about 1 ton of waste per day. Its advantages include 99.99% destruction of hazardous chemicals. It is not suitable, however, for small hospitals (200 beds or smaller).

Electron beam irradiation

Another way to kill infectious agents in medical waste and on reusable hospital equipment is to irradiate them with electrons produced by an accelerator similar to those used in cancer therapy. Nutek Corporation of Palo Alto, California, has developed such a unit, which can process 400 pounds of waste per hour without the need for shredding before treatment. The deferral of shredding until after sterilization eliminates the potential for releasing pathogens into the air.

A demonstration project in California is under review, and permit applications have been submitted in several other states. The advantages of electron beam irradiation include simplicity of operation and the fact that disinfection can be accomplished without heating the material (which can produce volatile organics). The main disadvantages are that the process does not destroy toxic chemicals and that shielding is needed for radiation protection.

Other project initiatives

In addition to supporting technology development and facilitating tech transfer, EPRI's collaborative medical waste disposal project is preparing an analysis of the health care industry for project participants and is scheduling a series of seminars to be cosponsored by host utilities. Some 30 utilities are now participating in the project. It also has advisors from the health care industry, including representatives of the American Hospital Association, the American Society of Hospital Engineers, the Centers for Disease Control, and public regulatory agencies.

Future activities will include broadening the project into a health care industry initiative. In addition to the ongoing work on medical waste, the expanded project will cover facilities (e.g., heating, ventilating, and air conditioning; lighting; cool storage) and energy management (e.g., power quality, drives, motors).

Waste Management

Ashalloys: Aluminum–Fly Ash Composites

by Dean Golden, Environment Division

The electric utility industry produces nearly 90 million tons of coal combustion by-products annually. The primary by-products are fly ash, bottom ash, slag, and flue gas desulfurization sludge. Currently only about 25% of this material is utilized; the remaining 75% goes to landfill or surface impoundments. The same percentages apply to fly ash, which accounts for over half of the total amount of combustion by-products. Only about 25% of the ash is used in construction or other applications; the bulk must be disposed of.

Although fly ash from volcanoes has been used in construction since Roman times (it was used, for example, to build the Coliseum in Rome), fly ash from coal-fired power plants has been used in construction in the United States for only the past 60 years. In recent developments, fly ash particles have been used to make materials called metal matrix composites (MMCs). A metal–fly ash composite offers the same functional properties as a solid metal casting while saving on metal costs.

More recently, fly ash from coal combustion has been combined with aluminum

ABSTRACT *EPRI is cosponsoring research on the use of fly ash from coal-fired power plants as a filler in aluminum alloys. This technology promises not only to help utilities reduce landfill disposal but also to provide materials offering improved properties and reduced manufacturing costs, in terms of both materials and energy. So far, researchers have successfully produced and cast these new composites—called Ashalloys—using standard foundry techniques, and tests of several key material properties have shown promising results. The goal of ongoing efforts is to develop a complete knowledge and technology base for the commercial production and use of Ashalloys.*

alloys to produce a class of MMCs called Ashalloys. Ashalloys offer the advantages of reducing disposal volumes for the electric utility industry, providing a high-value-added use of fly ash, and providing improved material properties at a reduced cost. Since the production of aluminum is energy-intensive, the replacement of aluminum by fly ash in Ashalloys promises significant energy savings.

Ashalloys could play a role in enhancing the competitiveness of foundries, which are important customers of many electric utilities. The U.S. foundry industry is located in the Great Lakes region. It is not uncommon for a utility to have a hundred or more foundries in its service territory. The melting of ingots for the casting of parts for automotive and other applications consumes considerable electricity. The foundry industry is very conscious of foreign competition for lower-cost components and is looking for ways to reduce costs. The substitution of fly ash as a filler in aluminum produces a composite with improved engineering characteristics (such as abrasion resistance) at a much lower cost.

This update focuses on the results of Ashalloy research performed at the University of Wisconsin at Milwaukee (UWM). Researchers there have produced aluminum–fly ash composites by using standard, inexpensive casting techniques and have evaluated the properties of the composites. They have also suggested potential applications for Ashalloys. This ongoing work at UWM is cosponsored by EPRI in tailored collaboration with Madison Gas & Electric Company, Niagara Mohawk Power Corporation, Northern Indiana Public Service Company, PSI Energy, and Wisconsin Electric Power Company.

Fly ash as additive

In recent years a new family of composites has been synthesized. Tailored to conserve materials and energy, these MMCs are metals or alloys reinforced with fibers or particles of a second material (dispersoids). In some cases the result can be improved properties. In other cases the additive acts merely as filler, reducing the cost without sacrificing the desirable properties of the original material. MMCs like aluminum–silicon carbide, aluminum-alumina, and aluminum-graphite are emerging as materials with great potential in the automotive and aerospace industries.

Although fillers have been used with polymeric materials in the past, filling metals with fly ash is relatively new. Most recently, fly ash has been used as a filler in light metals and alloys for manufactured products with potential applications in selected engineering components. Fly ash

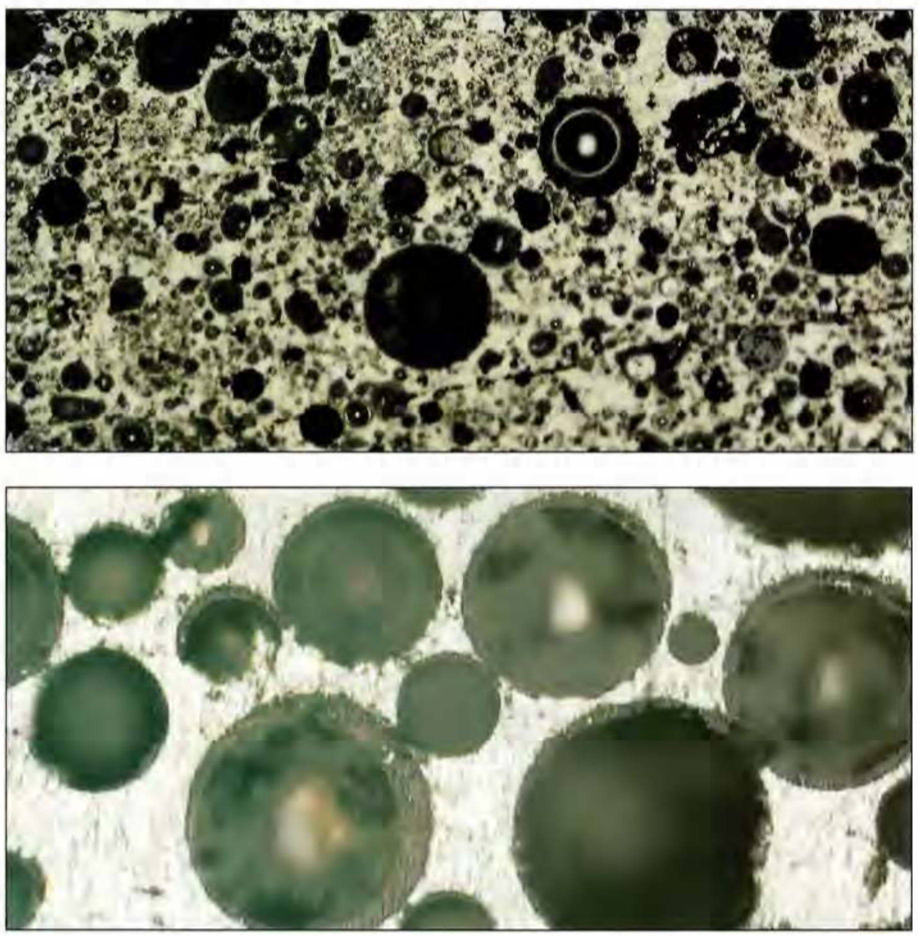
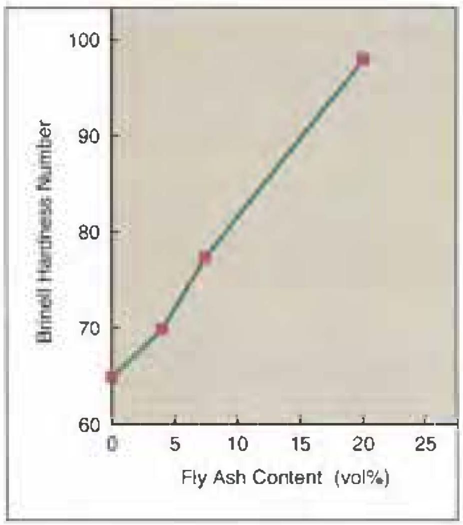


Figure 1 Photomicrographs of aluminum alloy–fly ash (20% by volume) composites: top, ×550; bottom, ×880. These show the even distribution of the spherical fly ash particles through the casting volume and the good interfacial contact achieved between the particles and the matrix.

particles are generally smaller than 150 µm in diameter (the thickness of two sheets of writing paper), although particle size distribution depends on the type of coal used. Most fly ashes consist mainly of solid, partly solid, or hollow spherical particles and so are an inexpensive source of microspheres, which are quite expensive to produce synthetically. Because of the spherical shape of a large fraction of fly ash particles, metal–fly ash composites have lower stress concentrations than composites using more-angular particles, such as silicon carbide particles.

Figure 2 The results of Brinell hardness tests (using a force of 3000 kg) show that the hardness of Ashalloy composite increases as the composite's fly ash content increases. This improvement is due to the fact that the fly ash particles are primarily aluminosilicates.



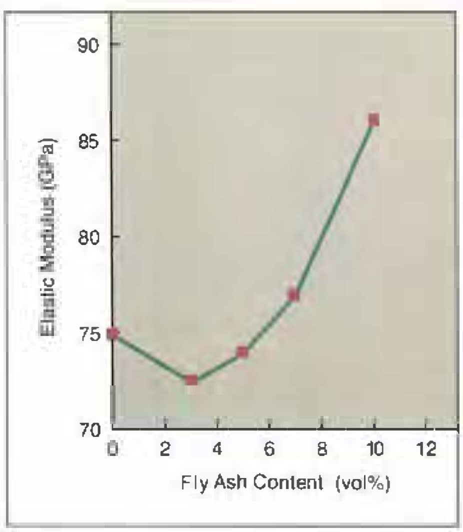


Figure 3 The tensile elastic modulus of Ashalloys increases as the fly ash content increases. A higher elastic modulus means greater stiffness, which can enable the production of components with smaller cross sections and hence reduced mass.

Processing of Ashalloys

MMCs reinforced with particles can be synthesized in several ways: powder metallurgy, casting, or spray deposition. Casting has the advantages of being relatively low in cost and capable of producing large, complex shapes. The UWM researchers developed an inexpensive casting technique to produce aluminum–fly ash composites containing various amounts of fly ash particles. Slurries of molten metal and fly ash were cast in suitable molds, where the metal solidified to produce composite components. Ashalloy ingots were also cast, with the fly ash content ranging up to 20% by volume.

Using various casting techniques, including sand, permanent mold, and gravity casting, the researchers produced automobile pistons and connecting rods from Ashalloys. These efforts demonstrated the feasibility of making Ashalloy castings of different shapes and dimensions.

Photomicrographs of sections of cast Ashalloys produced at UWM (Figure 1) reveal that the fly ash particles are evenly distributed through the casting volume, and that there is good interfacial contact between the fly ash particles and the solidified aluminum matrix.

Since standard foundry techniques require ingots to be remelted and recast into components, characteristics like melt fluidity are important. The researchers evaluated Ashalloy ingots for fluidity by melting and casting them into a variety of engineering components. The fluidity of the Ashalloys was adequate to make a variety of castings, and it compared favorably with the fluidity of a widely used aluminum casting alloy.

Cast aluminum alloy composites are often improved in performance and properties by a process of reheating and controlled cooling. Such thermal cycling was applied to Ashalloys, and the results indicate that the strength properties of aluminum–fly ash composites can be improved by heat treatment in the usual manner.

To evaluate the extrudability of Ashalloys, the researchers subjected an aluminum–fly ash (20% by volume) composite to hot extrusion. The results suggest that Ashalloy composites can be produced in extruded forms for a variety of applications, including lightweight structural applications.

Ashalloy properties

The researchers analyzed several mechanical and tribological (wear and friction) properties of cast Ashalloy samples to determine how the composite compares with the aluminum alloy matrix alone. In addition, they investigated the effect on various properties of increasing the volume percentage of fly ash (up to 20%). The properties examined include hardness, tensile strength, abrasive wear resistance, and compressive proof strength.

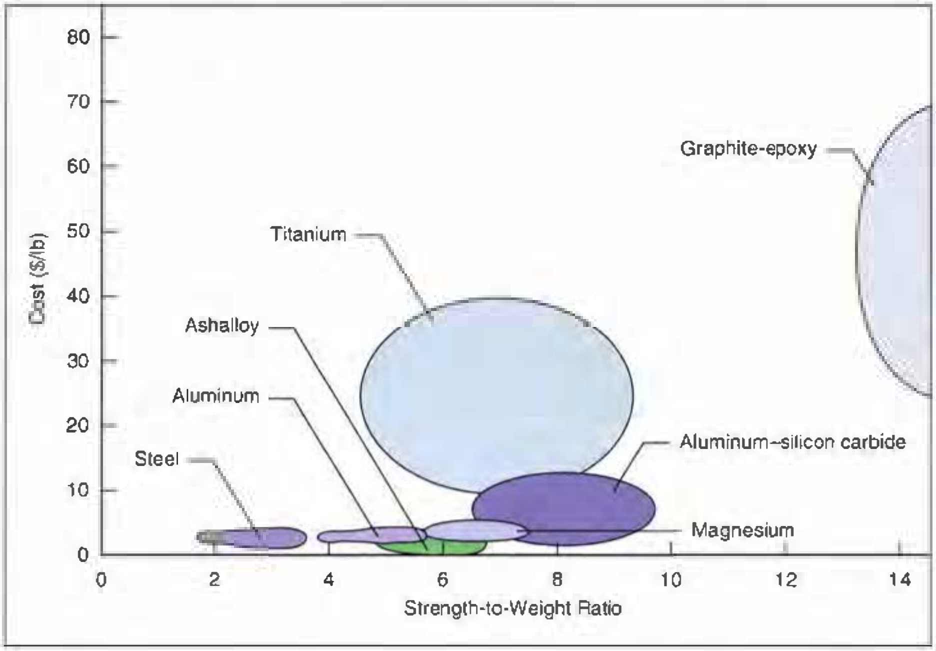
The addition of fly ash to the aluminum alloy matrix increased the material's Brinell hardness number. Figure 2 shows the nearly linear increase in hardness of the composite material as the volume percentage of fly ash increased from 0% to 20%. This increase is due to the hardness of the fly ash particles, which are basically aluminosilicates. The hardness of Ashalloys makes them desirable for use in certain engine components—pistons, for example.

Figure 3 shows the increase in the tensile elastic modulus of Ashalloys as the volume percentage of fly ash increased from 3% to 10%. A higher elastic modulus, which indicates greater stiffness, means that in cases where stiffness is the principal design criterion, as in golf clubs or other sports equipment, components with smaller cross sections can be fabricated. This means reduced component mass, which may offer additional advantages in rotating parts.

The abrasive wear resistance of Ashalloys was compared with the resistance of the aluminum alloy matrix alone by using a pin-on-disk wear test apparatus at various loads and speeds. The researchers found that adding fly ash (5% by volume) to the aluminum alloy significantly increased its abrasive wear resistance. As with the increase in hardness, the improvement in wear resistance is due to the presence of aluminosilicate fly ash particles.

Cast samples of Ashalloys that had been

Figure 4 Researchers compared Ashalloy composites with other materials by plotting each material's unit cost against its specific strength. The results reflect the material and energy cost savings promised by Ashalloys.



subjected to heat treatment and extrusion also were examined by electron microscopy and by physical and mechanical testing. The results were encouraging. Not only did the heat treatment cause no debonding of the fly ash particles, but it appeared to increase the hardness of the composite. Electron micrographs of extruded Ashalloys revealed alignment of the fly ash particles in the direction of extrusion. Although some particles had cracked, most of them retained their spherical shape and no debonding was evident. Compared with a standard cast composite, the extruded Ashalloys showed increased hardness and density. Of particular note was the increase (about 50%) in the ultimate tensile strength of the composite as a result of extrusion.

Finally, Ashalloys were compared with several other engineering materials by plotting each material's unit cost against its specific strength (Figure 4). The data indicate that Ashalloy composites have a significant advantage in material and energy costs over conventional alloys and metals.

Bright prospects for the future

There is significant promise for the fabrication of cast products from Ashalloys by using standard foundry techniques. Automotive components represent an especially promising area of application for Ashalloys and other MMCs.

In the near term, aluminum will replace steel in automobiles more rapidly than will MMCs. Two luxury cars, the Jaguar XJ220 and the Acura NSX, are already made from aluminum. By the turn of the century, the amount of aluminum in the average American car is expected to increase from the current 125 pounds to over 500 pounds. The German auto company Audi (the luxury division of the Volkswagen group) will introduce a car this spring that will feature an aluminum skeleton and body parts. In connection with that effort, Alcoa has built the world's first factory for the volume production of aluminum auto body structures.

Because aluminum is lighter than steel, aluminum cars offer better handling performance and lower fuel costs. Aluminum is also easily recycled. However, aluminum is more expensive than the steel it replaces, and cars made from it are more complicated to develop. EPRI believes that MMCs like Ashalloys will make a significant contribution to lowering the cost of aluminum cars while enhancing many engineering properties, including abrasion resistance (e.g., for braking systems and engine blocks) and sound-damping capabilities (e.g., for valve covers).

According to Professor P. K. Rohatgi of UWM, the principal investigator for EPRI's Ashalloy research, "The potential automotive applications of metal matrix composites, particularly aluminum matrix composites, are numerous. Although some composite components have reached the demonstration stage, there is still much work to do, and many barriers to conquer, before widespread application can be expected. These challenges include processing for specific properties, compiling property databases, and addressing recyclability."

This year, in cooperation with Ford Motor Company, EPRI will conduct pressure-die-casting trials using Ashalloys. Pulleys for power-steering systems will be fabricated. The competing aluminum–silicon carbide MMC sells for over $2 per pound. The price of Ashalloys is expected to be around $0.50 per pound, which will give the material a strong market advantage.

The UWM-EPRI research, which will continue through 1996, is addressing both the knowledge base and the technology base for Ashalloys. In theoretical modeling work, the UWM investigators are seeking to achieve standardized Ashalloy data sheets or calibration curves so that, for any set of material properties desired, an appropriate Ashalloy recipe can be readily identified. The ultimate goal of the research program is to develop a complete technology base for the commercial production and use of Ashalloys.

Future efforts to commercialize Ashalloys will involve three key steps: identifying machine parts and components for prototype production; establishing alliances with metal fabricators and foundries to sponsor the fabrication of test products for application (similar to the pressure-die-casting trials with Ford); and, in conjunction with the aluminum industry, developing engineering specifications for raw materials with fly ash, for product design, and for manufacturing promising product candidates. Commercialization in the auto industry is expected to occur first with such nonstructural parts as power-steering pulleys and valve covers. The incorporation of Ashalloys into auto body structural components may take five to seven years, given the typical lead times required for new models.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Advanced Water-Loop Heat Pump Equipment, Phase 2: Product Design and Development (RP3412-15)	$438,800 17 months	Trane Co./*W. Krill*
Low-Temperature Chlorine-Free Supermarket Refrigeration (RP3526-3)	$77,100 9 months	Foster-Miller/*M. Khattar*
Evaluation of Demand-Side Management Programs (RP3539-1)	$811,600 34 months	Xenergy/*R. Gillman*
Utility and Customer Communications Infrastructure Alternatives and Protocols (RP3567-1)	$400,000 10 months	First Pacific Networks/ *L. Carmichael*
Environmental and Energy Benefits of Electric Lawn Mowers (RP3598-1)	$315,900 14 months	Mills, McCarthy and Associates/*G. Purcell*
Methods and Equipment for Power Quality Improvement of Customer Systems With Disturbing Loads (RP3689-1)	$362,000 24 months	Louisiana State University/ *M. Samotyj*
DSManager Load Shape Database and Other Product Enhancements (RP3709-1)	$361,500 7 months	Electric Power Software/ *P. Sioshansi*
Demand-Side Management Community Initiative (RP3737-1)	$620,000 42 months	University of New Orleans/ *G. Heffner*
Electrical Systems		
Impact of Electric Vehicles and Dispersed Generation on Power Quality and Custom Power (RP3389-10)	$380,000 34 months	University of Texas/ *A. Sundaram*
Integrated Simulation of Power Electronic Converters in Power Systems (RP3389-15)	$183,300 23 months	University of Washington/ *A. Sundaram*
Mitigation of Nonconforming Load Effects to Improve System Operation (RP3555-1)	$68,400 37 months	University of Texas/ *P. Hirsch*
Hybrid Filters for Power System Harmonics (RP3556-4)	$59,700 12 months	University of Minnesota/ *A. Edris*
Distribution System Reliability to Improve Power Quality (RP3669-1)	$4,300,000 93 months	Geomet Data Services/ *R. Bernstein*
Distribution Automation/Demand-Side Management Demonstration (RP3674-2)	$1,000,000 29 months	United Power Association/ *W. Blair*
EGEAS Version 7.0 Enhancements (RP3681-1)	$495,400 33 months	Stone & Webster Management Consultants/ *R. Adapa*
Interface for EPRI Operator Training Simulator (RP3731-2)	$80,000 13 months	Salt River Project/ *G. Cauley*
Advanced Power Transformer Demonstration (RP3792-1)	$128,400 36 months	Delmarva Power & Light Co./*S. Lindgren*
Study of System Operating Impacts of FACTS Technologies (RP3832-7)	$124,000 11 months	New York Power Authority/ *A. Vojdani*
Environment		
Milliken Mist Eliminator Testing (RP9017-2)	$55,300 6 months	Radian Corp./*R. Rhudy*
Impoundment Closure Research (RP9020-2)	$277,100 30 months	Science & Technology Management/*I. Murarka*
Ash Impoundment Closure Study (RP9020-3)	$293,800 8 months	Atlantic Environmental Services/*I. Murarka*
Compact Hybrid Particulate Collector Demonstration (RP9027-1)	$11,311,000 46 months	TU Electric/*R. Chang*
Assessment of Coal Cleaning as an Air Toxics Control Measure (RP9028-1)	$77,900 18 months	CQ Inc./*B. Toole-O'Neil*
PISCES Air Toxics Testing at Kansas City Power & Light's Iatan Station (RP9028-14)	$229,600 6 months	Radian Corp./*P. Chu*
Laboratory and Field Studies on Leachate Characteristics at a Dry Ash Landfill (RP9032-1)	$64,900 11 months	University of Kentucky Research Foundation/ *J. Goodrich-Mahoney*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Exploratory & Applied Research		
Particle Turbulence Interactions Near Flow Boundaries (RP8034-2)	$239,600 36 months	University of California, Santa Barbara/ *J. Maulbetsch*
Combined Ultrahigh-Voltage/Electrochemical Studies of Corrosion and Stress Corrosion Cracking (RP8044-1)	$389,200 36 months	University of North Texas/ *J. Stringer*
In-service Degradation of Fossil Plant Materials (RP8046-4)	$166,100 17 months	Failure Analysis Associates/ *R. Viswanathan*
Electric Power System Bifurcations and Chaotic Dynamics (RP8050-6)	$178,000 31 months	Hsiao-Dong Chiang/ *T. Schneider*
Novel Electroorganic Syntheses in Supercritical Electrolytes (RP8060-4)	$108,500 25 months	University of Detroit, Mercy/ *R. Weaver*
Interfacial Aspects of Synthesis of Nanoparticles in Microemulsions Relevant to Superconductors and Varistors (RP8065-5)	$241,000 34 months	University of Florida/ *D. Von Dollen*
Generation & Storage		
2-MW Molten Carbonate Fuel Cell Demonstration Project (RP3377-1)	$5,125,400 47 months	City of Santa Clara, California/*E. Gillis*
Substation Predictive Maintenance Program (RP3485-3)	$320,000 17 months	Bogan/*R. Colsher*
Computerized Weld Information System (RP3485-4)	$258,000 9 months	Kaman Sciences Corp./ *R. Colsher*
Wood Cofiring, Phase 2: Analysis and Testing (RP3576-2)	$525,000 13 months	Ebasco Environmental/ *E. Hughes*
Large Air-Cooled Generators Driven by Combustion Turbines: Generic Issues (RP3577-2)	$104,400 12 months	Electro Mechanical Engineering Associates/ *J. Stein*
Development of Fireside Performance Indices: Convective Pass Fouling and Fly Ash Collectibility (RP3579-2)	$360,000 31 months	University of North Dakota/ *A. Mehta*
Planar Solid Oxide Fuel Cell (RP3608-1)	$765,000 19 months	ZTEK Corp./*R. Goldstein*
Nuclear Power		
In Situ Piping Rehabilitation (RP3052-10)	$338,600 19 months	Northeast Utilities Service Co./*G. Adams*
Obsolete-Items Database, Phase 2 Implementation (RP3186-30)	$53,500 5 months	Karta Technology/ *J. Munchausen*
In-pile Fuel Corrosion Tests With Zinc (RP3223-8)	$1,188,500 36 months	Institutt for Energiteknikk/ *S. Yagnik*
CREDIT Code Development (RP3342-1)	$50,000 6 months	Accident Prevention Group/ *A. Singh*
Life-Cycle Management Decision Analysis (RP3343-15)	$179,600 11 months	Janus Management Associates/*M. Lapides*
On-line Iron Probe Field Testing (RP3388-7)	$84,800 11 months	Babcock & Wilcox Co./ *P. Millett*
Applicability of Vessel Thermal Annealing (RP3475-2)	$94,800 5 months	Westinghouse Electric Corp./*R. Carter*
Application of Risk Technologies to Technical Specifications (RP3477-2)	$516,900 36 months	PLG, Inc./*F. Rahn*
Application of Risk and Reliability Methods to Regulatory Issues (RP3477-5)	$64,100 11 months	Quadrex Energy Services Corp./*F. Rahn*
Integral Fast Reactor Fuel-Cycle Demonstration (RP3764-1)	$2,000,000 16 months	Argonne National Laboratory/*E. Rodwell*
Integrated Maintenance Program for Maintenance Rule Compliance (RP3770-1)	$550,200 30 months	Erin Engineering & Research/*D. Worledge*
Integrated Maintenance Program for Maintenance Rule Compliance (RP3770-2)	$612,400 30 months	Quadrex Corp./ *D. Worledge*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities. Reports will be provided to others in the United States for the price listed or, in some cases, under the terms of a license agreement. Those outside the United States should contact the Distribution Center for price information.

CUSTOMER SYSTEMS

Monitoring Chemigation With Single-Board Computers
TR-100447 Final Report (RP2782-4); $200
Contractors: Oregon State University; National Food & Energy Council, Inc.
EPRI Project Managers: A. Amarnath, O. Zimmerman

Customer 20/20: Breaking the Future Trap, Vol. 1—Assuring Future Customer Options Through Scenario Planning
TR-101694-V1 Final Report (RP3165-10); $200
Contractor: Global Business Network
EPRI Project Manager: M. Evans

Customer 20/20: Breaking the Future Trap, Vol. 2—Scenario Development Sourcebook
TR-101694-V2 Final Report (RP3165-10); $200
Contractor: Global Business Network
EPRI Project Manager: M. Evans

Customer 20/20: Breaking the Future Trap, Vol. 3—Scenario Development Toolkit
TR-101694-V3 Final Report (RP3165-10); $200
Contractor: Global Business Network
EPRI Project Manager: M. Evans

Lessons Learned in Commercial-Sector Demand-Side Management
TR-102551 Final Report (RP3374-1, -2); $200
Contractors: RCG/Hagler, Bailly, Inc.; Xenergy, Inc.
EPRI Project Manager: M. Evans

Principles and Practice of Demand-Side Management
TR-102556 Final Report (RP2342-16); $200
Contractor: Barakat & Chamberlin, Inc.
EPRI Project Managers: M. Evans, P. Meagher

ELECTRICAL SYSTEMS

Survey of Residential Magnetic Field Sources, Vols. 1 and 2
TR-102759-V1, TR-102759-V2 Final Report (RP3335-2); $200 each volume
Contractors: General Electric Co.; Enertech Consultants; Electric Research and Management
EPRI Project Managers: J. Dunlap, G. Rauch

HVDC Transmission Line Reference Book
TR-102764 Final Report (RP2472-3); $5000
Contractor: High-Voltage Transmission Research Center
EPRI Project Manager: J. Hall

Analysis of Performance Accelerator Running ETMSP
TR-102856 Final Report (RP8010-31); $200
Contractor: Performance Processors, Inc.
EPRI Project Managers: G. Cauley, J. Maulbetsch

Castable Substation Insulators
TR-102868 Final Report (RP2841-1); $5000
Contractor: Battelle Memorial Institute
EPRI Project Manager: G. Addis

ENVIRONMENT

Proceedings: EPRI Cancer Workshop II on Laboratory Research
TR-101749 Proceedings (RP2965-99); $200
EPRI Project Manager: C. Rafferty

Toxicity Characteristic Leaching Procedure (TCLP) Analysis of Crankcase Oils and Oil Residues From the Electric Utility Industry
TR-101812 Final Report (RP2879-18); $200
Contractor: Envirosystems, Inc.
EPRI Project Manager: J. Goodrich-Mahoney

State-of-the-Art Assessment of SNCR Technology
TR-102414 Topical Report (RP2869-14); $500
Contractor: Fossil Energy Research Corp. under contract to Radian Corp.
EPRI Project Manager: J. Stallings

Remedial Technologies for Petroleum-Contaminated Soils and Groundwater, Second Edition
TR-102664 Final Report (RP2795-1); $200
Contractors: Roy F. Weston, Inc.; University of Massachusetts
EPRI Project Manager: M. McLearn

GENERATION & STORAGE

Power Plant Modification Evaluation Using the Plant Modification Operating Savings (PMOS) Model
TR-101715 Final Report (RP1184-31); $500
Contractor: Decision Focus, Inc.
EPRI Project Manager: D. O'Connor

Survey of Cost-Effective Photovoltaic Applications at U.S. Electric Utilities
TR-102648 Final Report (RP3258); $200
Contractor: Craig D. Eastwood
EPRI Project Manager: J. Bigger

Small-System Performance Under High Wind Plant Penetration
TR-102784 Final Report (RP2790-4); $200
Contractor: Electrotek Concepts, Inc.
EPRI Project Managers: E. DeMeo, J. Birk

Proceedings: 1992 Feedwater Heater Technology Symposium
TR-102923 Proceedings (RP2504-11); $200
Contractor: Karta Technology, Inc.
EPRI Project Manager: J. Tsou

Guidelines on Cycle Chemistry for Fluidized-Bed Combustion Plants
TR-102976 Final Report (RP979-29); $200
Contractor: Sargent & Lundy
EPRI Project Manager: B. Dooley

NUCLEAR POWER

Circuit Breaker Maintenance, Vol. 2, Part 1: Medium-Voltage Circuit Breakers, ABB HK Models
NP-7410-V2P1 Final Report (RP2814-67); $12,000
Contractor: Grove Engineering, Inc.
EPRI Project Manager: J. Sharkey

Comparison of the Guidance in the SQUG Generic Implementation Procedure and the EPRI Seismic Margin Methodology
TR-101055 Final Report (RP2722-30); $200
Contractors: Jack R. Benjamin & Associates, Inc.; MPR Associates, Inc.
EPRI Project Manager: R. Kassawara

Development and Use of an In-Pile Loop for BWR Chemistry Studies
TR-102248 Final Report (RP2295-4); $200
Contractor: Massachusetts Institute of Technology Nuclear Reactor Laboratory
EPRI Project Managers: R. Pathania, C. Wood

Stiffness of Reinforced Concrete Walls Resisting In-Plane Shear
TR-102731 Final Report (RP3094-1); Tier 1, $200; Tier 2, license required
Contractor: Sozen & Moehle
EPRI Project Manager: H. Tang

Trial Application of Guidelines for Nuclear Plant Response to an Earthquake
TR-102782 Final Report (RP2848-21); $200
Contractors: MPR Associates, Inc.; Yankee Atomic Electric Co.; Toledo Edison Co.
EPRI Project Manager: R. Kassawara

Nonlinear Analysis of High-Level Vibration Tests of a Modified PWR Primary Coolant Loop Model
TR-102783 Final Report (RP2350-2); $200
Contractors: Rockwell International; Robert L. Cloud & Associates
EPRI Project Manager: H. Tang

Analysis of Fatigue Crack Growth Rate Data for A508 and A533B Steels in LWR Environments
TR-102793 Final Report (RP2006-20); $200
Contractor: Modeling and Computing Services
EPRI Project Manager: J. Gilman

Analysis of A508 Class 2 and A533B Pressure Vessel Steel Fatigue Tests in Air
TR-102794 Final Report (RP2006-4); $200
Contractor: Failure Analysis Associates
EPRI Project Manager: J. Gilman

FATDAC: Fatigue Data Analysis Code
TR-102795 Final Report (RP2006-4); $200
Contractor: Failure Analysis Associates
EPRI Project Manager: J. Gilman

Environmental Acceleration of Fatigue Crack Growth in Reactor Pressure Vessel Materials, Vols. 1 and 2
TR-102796 Final Report (RP1325-1); Vols. 1 and 2, $200 each volume
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: J. Gilman

EPRI Events

MARCH

29–April 1
Nondestructive Evaluation of Fossil Plants
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

APRIL

5–6
Global Warming: A Call for International Coordination
San Francisco, California
Contact: Colleen Hyams, (415) 855-2143

5–7
Direct DSM Marketing
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

14–15
Fire Protection Workshop
San Francisco, California
Contact: Lori Adams, (415) 855-8763

26–28
3d Disaster Preparedness Conference
St. Louis, Missouri
Contact: Kathleen Lyons, (415) 855-2656

26–29
Transformer Performance Monitoring and Diagnostics
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

MAY

2–3
Load Management: Dynamic DSM Options for the Future
Houston, Texas
Contact: Paul Meagher, (415) 855-2420

3–5
Heat Rate Improvement
Baltimore, Maryland
Contact: Susan Bisetti, (415) 855-7919

10–11
Decision Analysis for Environmental Risk Management
Washington, D.C.
Contact: Bob Goldstein, (415) 855-2593

10–13
Decision Quality/Decision Analysis Seminar and Workshop
Newport, Rhode Island
Contact: Susan Marsland, (415) 855-2946

11–13
NO_x Controls for Utility Boilers
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

12–13
Decision Analysis for Environmental Risk Management
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

16–20
Applications of Static Compensators and Other FACTS Power Flow Controllers
Madison, Wisconsin
Contact: Bill Long, (608) 262-2061

17–19
FBC for Power Generation
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

17–19
6th Predictive Maintenance Conference
Philadelphia, Pennsylvania
Contact: Lori Adams, (415) 855-8763

19–20
Improving Building Systems in Hot and Humid Climates
Arlington, Texas
Contact: Susan Swanson, (409) 862-2291

JUNE

1–2
Customer Value Deployment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

2–3
Integrated DSM/T&D
Lake George, New York
Contact: Phyllis Firebaugh, (214) 556-9545

6–8
ISA POWID/EPRI Controls and Instrumentation Conference
Orlando, Florida
Contact: Lori Adams, (415) 855-8763

27–29
Technology Delivery Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

29–July 1
Service Water Systems Reliability Improvement
St. Louis, Missouri
Contact: Susan Otto, (704) 547-6072

JULY

10–14
Mercury as a Global Pollutant
Whistler, British Columbia
Contact: Pam Turner, (415) 855-2010

12–13
Needs-Driven Program Design
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

24–26
International Conference on Low-Level Waste
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

26–29
ASME/EPRI Radwaste Workshop
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

AUGUST

1–2
Rate Design in the 1990s
Boston, Massachusetts
Contact: Phyllis Firebaugh, (214) 556-9545

2–4
Direct DSM Marketing
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

3–4
Nuclear Plant Performance Improvement Seminar
Charleston, South Carolina
Contact: Susan Otto, (704) 547-6072

17–19
Effects of Coal Quality on Power Plants
Charleston, South Carolina
Contact: Susan Bisetti, (415) 855-7919

24–26
4th International Symposium on Magnetic Bearings
Zurich, Switzerland
Contact: Tom McCloskey, (415) 855-2655

30–September 1
Cooling Towers and Advanced Cooling Systems
St. Petersburg, Florida
Contact: Lori Adams, (415) 855-8763

SEPTEMBER

7–9
4th Conference on Cycle Chemistry in Fossil Plants
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

7–9
4th International Conference on Rotor Dynamics
Chicago, Illinois
Contact: Tom McCloskey, (415) 855-2655

8–9
Decision Analysis for Environmental Risk Management
Palo Alto, California
Contact: Bob Goldstein, (415) 855-2593

14–15
11th Annual Operational Reactor Safety Engineering and Review Groups Workshop
Dallas, Texas
Contact: Denise O'Toole, (415) 855-2259

14–16
Fossil Plant Cycling
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

19–21
Fuel Supply Seminar
Chicago, Illinois
Contact: Susan Bisetti, (415) 855-7919

OCTOBER

3–6
Pollution Prevention Seminar
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

19–21
13th Conference on Coal Gasification Power Plants
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

24–27
Power Quality Applications, 1994
Amsterdam, the Netherlands
Contact: Carrie Koeturius, (510) 525-1205

EPRI JOURNAL

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

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