Will Natural Gas Deliver for Utilities?

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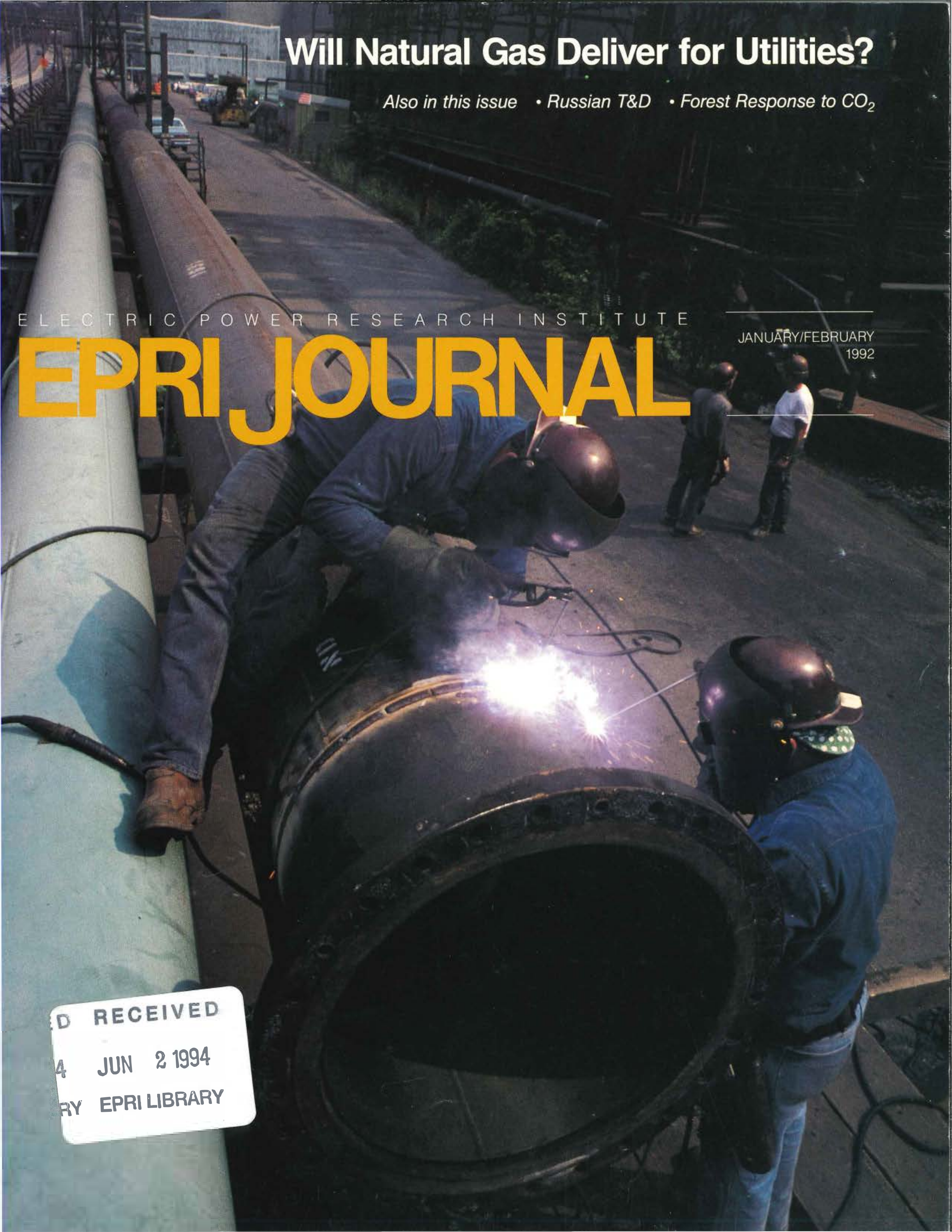

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Cover: The question of whether there will be sufficient pipeline capacity in place to serve a substantially expanded utility market for natural gas is a key point in the debate over future gas-fired generation. (Photo by Lynn Johnson/Black Star)

EDITORIAL

Understanding the Gas Dilemma

The capability of the U.S. natural gas industry to continue to discover, recover, and deliver increasing volumes of natural gas at economically competitive prices for electric power generation has become one of the major issues facing utility executives today. Projecting the future is always a dangerous endeavor, and trying to anticipate future trends for an industry that has undergone the metamorphosis of 13 years of federal deregulation is a task that cannot and should not be taken lightly.

Current competitive prices and the apparent adequate short-term supply and deliverability of natural gas to many regions are resulting in a significant dilemma for utility decision makers.

The present business environment requires regulated electric utility companies to compete with independent power producers while at the same time complying with increasingly stringent environmental regulations. Natural gas—because of its extremely desirable environmental performance characteristics and current low prices (less than $3 per million Btu)—is a particularly attractive fuel in many regions for repowering existing steam plants as well as for fueling new power generating capacity. However, many utility managers remember the disruptions to their companies—and to their customers—created by the 1978 Fuel Use Act and the period of rapid price increases experienced in the early to mid 1980s.

The dilemma facing today's utility executive, therefore, is how to exploit the significant opportunities provided by low-cost natural gas to meet customer needs with minimal environmental impact while at the same time protecting the company against the risks posed by potential price increases and/or supply disruptions that could result from large increases in gas consumption for electric power generation.

The Institute's current R&D program is addressing this situation, developing tools and information to help member utilities assess the opportunities and risks associated with increasing their use of natural gas on a regional basis. Early products from this research activity include estimates of potential long-term global supplies that are economically recoverable; mechanisms for coordinating gas and electric operations to minimize short-term fuel supply disruptions; information on the cost of storing gas; and software tools to optimize gas purchasing/contracting strategies.

On the technology side, EPRI is furthering the development of advanced combustion turbines and fuel cells capable of significantly increasing the efficiency with which gas is converted to electricity. We are also developing systems that have the capability to generate fuel gas from coal—technology that will provide insurance against natural gas prices becoming too high for economic bulk power generation.

Through these and future efforts, EPRI seeks to provide its members with the capability to take advantage of the potential opportunities offered by gas while minimizing the risks.

Michael J. Gluckman
Director, Integrated Energy Systems Division

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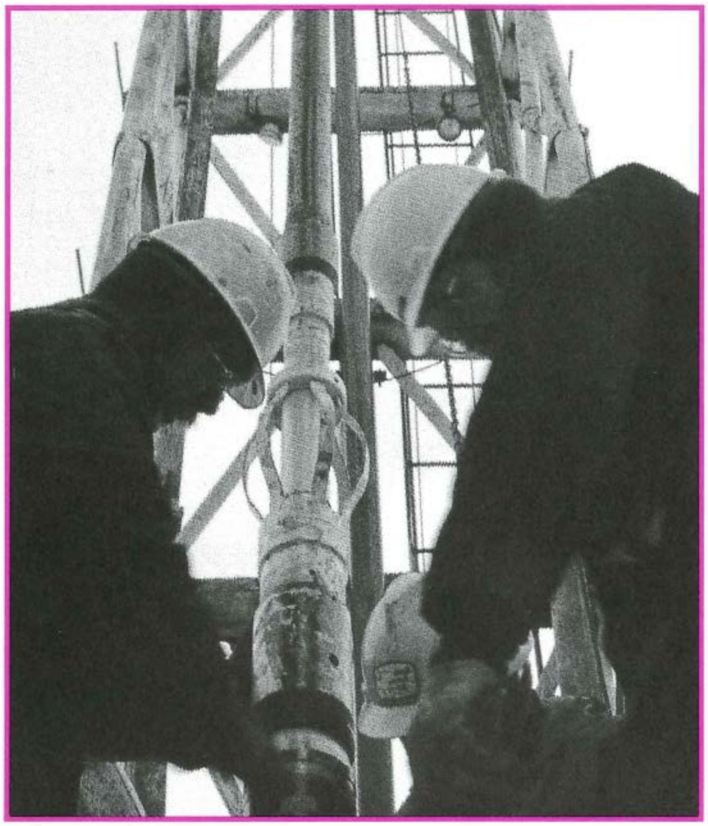
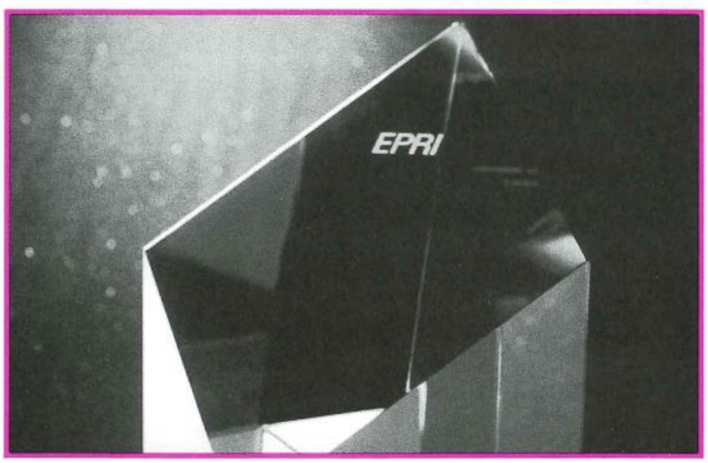


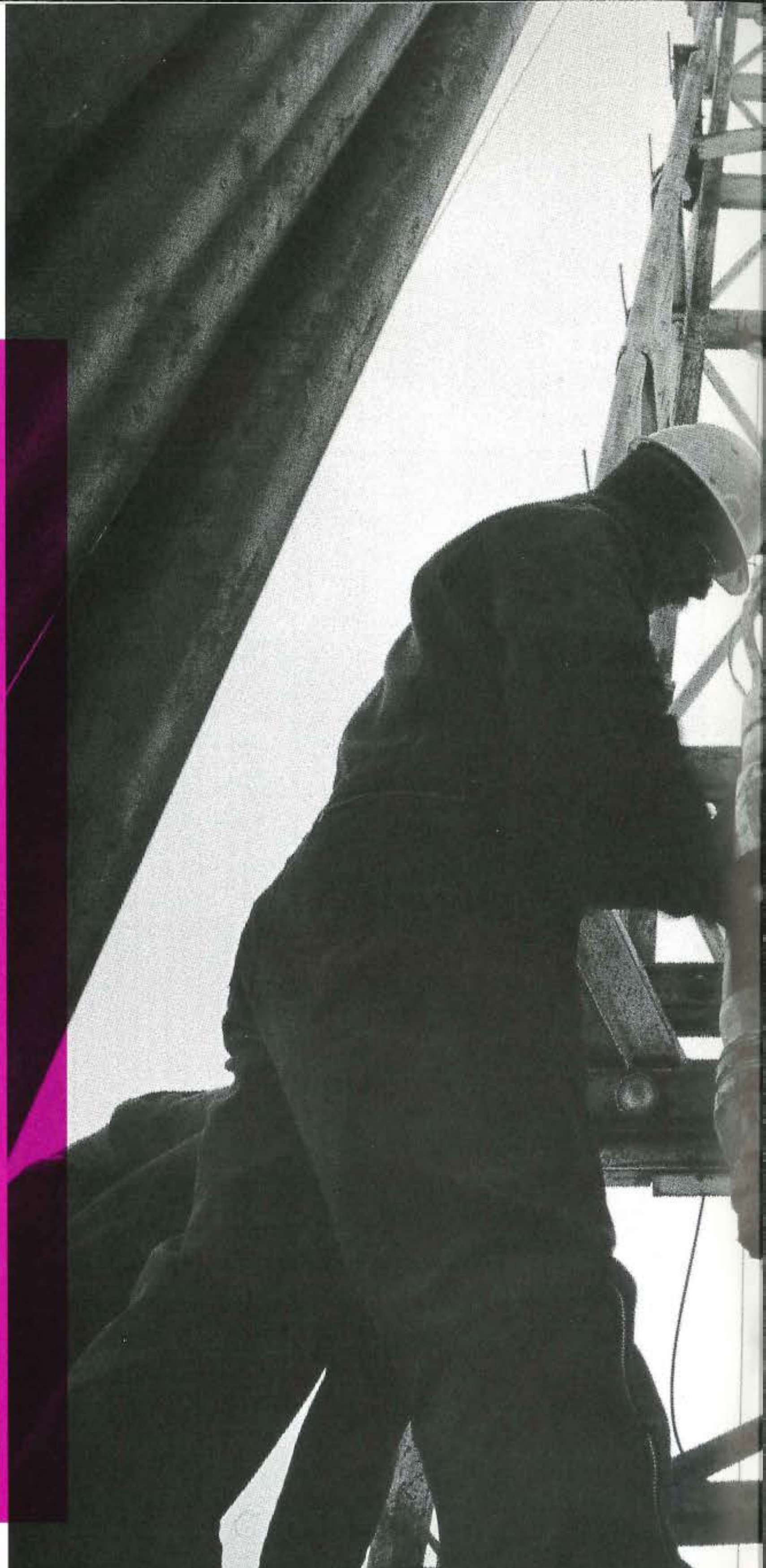
4 Natural Gas

16 Achievement Awards



THE STORY IN BRIEF

Forecasters predict that natural gas will be the dominant fuel choice for utility capacity additions in the coming decade and that power generation will be by far the largest growth market for gas sales. While gas's low emissions, high efficiency potential, and present low cost argue persuasively for a surge in gas-fired generation, many utilities have been slow to commit to a gas future, citing reasoned concern about long-term price trends and the ability of gas suppliers to deliver the fuel where and when it will be needed. Meanwhile, the relatively low cost of gas-fired units is providing an opportunity for independent power producers to compete strongly with utilities for generation contracts. EPRI studies suggest that a sound, competitive strategy will be based not on how much gas a utility burns, but rather on how this capacity fits into its overall generating mix at various fuel price levels. Gas suppliers will need to pay special attention to the operating needs of power generators if they are to solidify this important market.



Natural Gas for Ut

Ron May

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AS LONG AS IT IS AVAILABLE AND ATTRACTIVELY PRICED, natural gas would seem to be the ideal fuel for electric power generation. No other fuel matches its attractiveness in terms of the speed and modularity of adding new generating capacity, its efficiency potential, or its low emissions. These advantages, coupled with continued low gas prices, have led many to believe that natural gas could be the growth fuel of the 1990s and perhaps for several decades to come.

In a recent report by the New York–based consulting group National Economic Research Associates, economist Marion Stewart says, "Our long-held view that electric utility gas demand will soar in the late 1990s is widely shared by other forecasters, government agencies, and many utilities. It therefore seems something of a puzzle why so few utilities seem to have moved aggressively to secure long-term gas supplies."

Reflecting on the utility industry's position, Howard Mueller, program manager for utility planning methods in EPRI's Integrated Energy Systems Division, answers the question in these terms: "In recent history, the electric utility industry has made a considerable effort to get off of gas, partly in response to national policy directives and legislation and partly in response to economics. Spot prices for gas remain low, but a number of utility executives may be uneasy about relying heavily on gas for new generation because of the risk of gas price increases or supply disruptions. On the other hand, utilities may find that gas may remain a viable option for many of their generating needs. And they are increasingly finding it necessary to consider generating-capacity options that will remain competitive with independent power producers [IPPs] in generation bidding programs. IPPs themselves, more often than not, choose gas as the most competitive way to win generation bids, which puts even more emphasis on gas."

These factors, especially the uncertain future of natural gas markets, raise legitimate concerns about the riskiness of current utility natural gas strategies. And the questions are more complex than whether present gas reserves are large enough to serve the added demand. Much of the utility wariness centers on the supply infrastructure and dynamics of the marketplace. Can existing pipeline capacity handle future utility needs? Can new pipelines be approved and built in time to fuel new gas-fired capacity? Will gas producers invest in the drilling programs needed to supply utilities with gas on a reliable and timely basis further out in the future? Will long-term supply contracts be available at reasonable cost, or will utilities have to rely on short-term purchasing strategies? Will prices surge when utilities commit to new gas-fired generation? And finally, if all the forecast growth in utility demand for gas materializes in the years ahead, what will be the implications for the cost and reliability of electricity itself? Reassurances from the gas supply industry notwithstanding, past experience causes the electric utility industry to take these questions very seriously.

Despite the risks, gas-fired generation poses a number of significant opportunities that make it very attractive to utility planners and executives. Its lower capital cost, short lead time, and modular size make it less financially risky and less subject to load and other business uncertainties. Low capital cost and currently low fuel cost, combined with the dramatically improved operating efficiencies of new combustion turbine–based generating units, provide an opportunity for lower-cost electricity generation. Moreover, gas offers important environmental advantages. All of these factors have contributed to a substantial increase in interest in gas-fired generation and gas planning issues.

Comments Mueller: "One of the key objectives of our R&D program is to help utilities better understand the opportunities and risks associated with the increased use of gas on a regional and local basis."

Off again, on again

Major change has been a regular part of the gas business for the past quarter century. With the advent of integrated interstate pipeline systems, gas consumption by all consumers (including utilities) was booming by the 1960s. It rose to account for as much as a third of total U.S. energy consumption by 1970, and in 1972 gas use by volume reached a record level of 22.7 trillion cubic feet, which has not been equaled since. During the 1960s and early 1970s, gas's low, federally regulated wellhead price led to diminishing supplies for the interstate market, resulting in shortages for many industrial and utility users. The increased use of nuclear power and coal-fired generation by utilities, a trend that began in the 1960s and grew rapidly in the 1970s, helped dampen electric utility demand for gas.

The perceived shortage of gas led, in 1978, to a congressional mandate for a phaseout of the existing use of gas by utilities and a prohibition against new utility and industrial gas-fired plants. This prohibition remained in effect for nearly a decade. Many users of gas took to heart the message that it was to be avoided as a future utility fuel option. Gas was thought to be such a premium fuel that it should not be used for power generation, especially since domestic coal was plentiful and inexpensive. Moreover, the phased removal of wellhead price controls that began in 1978 resulted in rising gas prices that drove many industrial users away—to electricity-based production methods, to overseas production, or out of business. Much of the market for gas that was driven away has not returned, leading to the famed gas bubble of surplus deliverability—a bubble that has become a 10-year "gas sausage," in the phrase of one senior industry expert.

Over the past five years, gas's star has been rising again. Gas has been growing cheaper than oil ever since prices began to be shaped less by competition with oil and more by competition between gas producers, a situation brought on by surplus deliverability. In addition, no new nuclear plants are likely to be built in the near term. Environmental concerns over the use of coal—first with respect to the 1990 Clean Air Act Amendments' requirements for reduced emissions of sulfur and nitrogen oxides and, more recently, to global climate change—will result in increases in the cost of building and operating new coal-fired generating facilities.

Global environmental activists are pushing to limit or forestall substantial increases in the use of coal in future conventional power plants and in other applications as a way to stem the rise of carbon dioxide levels in the atmosphere. Many are advocating the use of natural gas as a near-term alternative, noting that its combustion results in the release of about half as much CO_2 as coal combustion. It is also worth noting, however, that gas itself—methane—is a far more potent greenhouse gas than CO_2: its global warming potential is more than 20 times greater than that of CO_2. Gas production and delivery result in the release of some methane into the atmosphere, but arguments that gas could play a major role in limiting greenhouse gas emissions depend on the assumption that very little of it leaks before it is burned.

Meanwhile, the Bush administration's National Energy Strategy, embodied in legislation that failed in the Senate last fall but that may be largely reincarnated this year, includes proposals to encourage increased North American gas production, streamline federal approval for new interstate pipelines, deregulate pipeline sales, and allow greater access to pipeline carriage by the highly competitive production side of the industry.

Price reflects supply and demand

Gas accounts for as much as one-fifth of the world's energy consumption, and its global geographic distribution (both reserves and estimated resources) is far broader than oil's. Most observers in this country agree that there is very likely a lot of gas available (see sidebar). According to various estimates, the North American supply that is economically recoverable with today's technology is well over 50 years' worth at the present rate of consumption.

The decade-long surplus in available capacity and deliverability has been reflected in declining prices for gas. As for its use as a utility generating fuel, given the recent depressed spot market prices, gas would have to increase in cost by a factor of more than 3 over its seasonal low price to pass the point beyond which the conversion of gas-fired capacity to integrated gasification–combined-cycle generation would be economically more attractive (see IGCC sidebar).

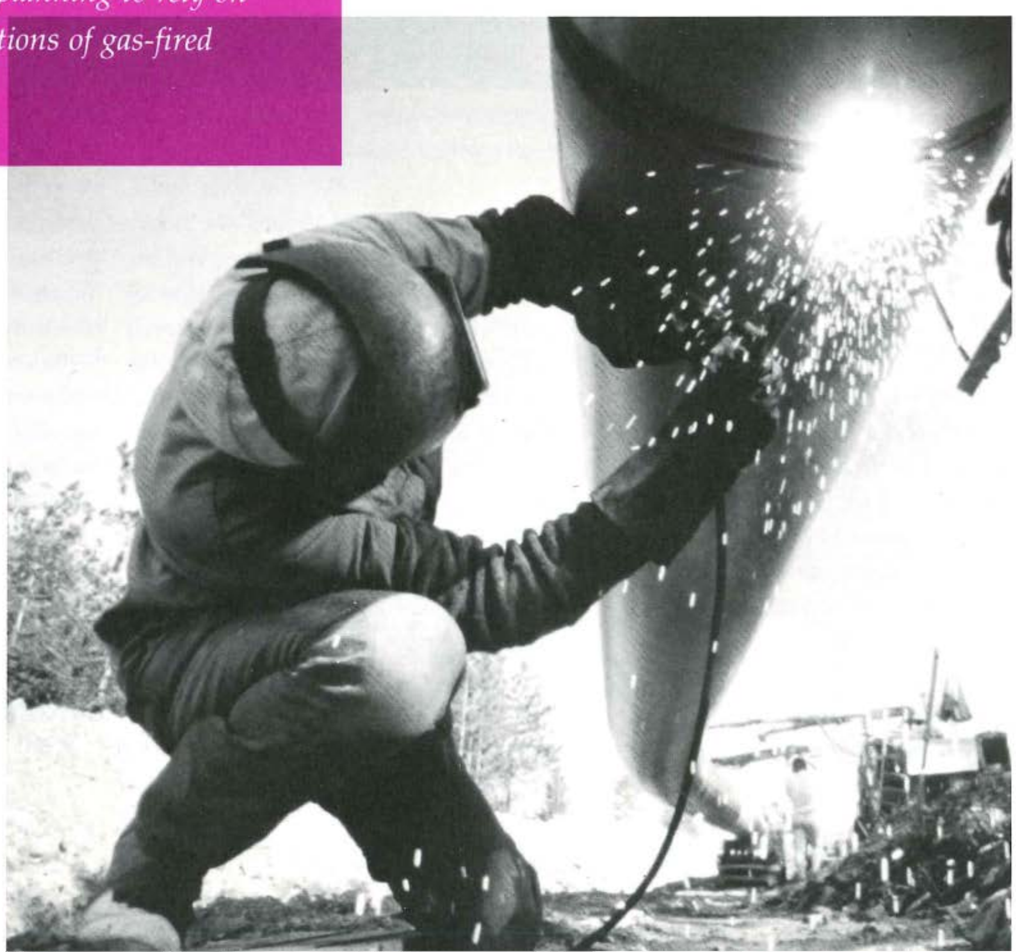
People knowledgeable about the gas market seem to agree that if the projected demand growth for gas in electricity generation and in the gas industry's hoped-for new market—as a compressed alternative fuel in buses, trucks, and automobiles—begins to materialize later this decade, it will most likely exert upward pressure on gas prices. But how much of a rise and how fast are very much unknown risks.

Those who take an optimistic view of the future of gas as a generating fuel tend to think that the soft buyer's market will continue, with current and future prices being more a function of the uncertain but expanding estimated long-term resource base. But those with a more pessimistic outlook think that once demand begins to rise and the current deliverability surplus is reduced as utilities commit to new gas-fired plants, the buyer's market could quickly change to one where price is subjected to heavy upside pressure from gas producers and transporters.

EPRI founder and president emeritus Chauncey Starr says that today's low gas prices may represent an attractive short-term opportunity for electric utilities, but that, ultimately, price is set in the market. "Utilities are literally being sucked into using more gas now because the spot price is very low," says Starr. "But as the available and planned pipeline capacity is committed and demand begins to use up the surplus wellhead production, the price will go up and utilities know it. Some say they're having trouble getting 20-year gas supply contracts even close to today's prices because the gas producers know that five years from now, they may be able to charge a lot more.

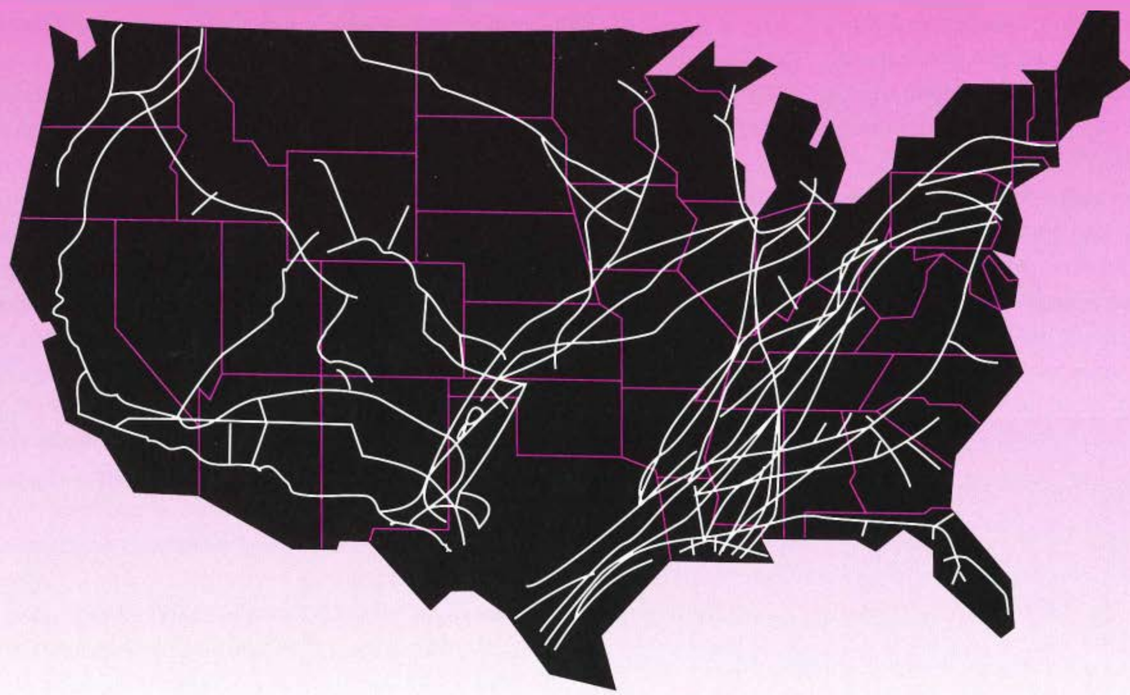
Supply Infrastructure: Can It Deliver?

The adequacy of the natural gas industry's existing and planned production, pipeline, and delivery systems to meet the projected growth in demand for gas for power generation is a concern of utilities that are planning to rely on substantially greater proportions of gas-fired capacity in the future.



Iroquois Gas Transmission System

AN EXPANDING PIPELINE NETWORK Some 1.2 million miles of interstate pipelines crisscross America, carrying natural gas from producing areas in the Gulf of Mexico, Texas, Louisiana, the midcontinent region, and Alberta, Canada, to traditional demand centers in metropolitan areas. Major new pipeline projects in California, Florida, New York, and elsewhere will help reduce gas transmission bottlenecks that sometimes constrain deliverability and will help serve the expected growing market for gas in power generation.



What that price is will depend on the opportunistic situation that exists then."

Deliverability can be a constraint

Its global environmental appeal notwithstanding, natural gas remains largely a regional and domestic energy resource in this country because of the cost of building new land-based pipelines and pumping gas over long distances or, alternatively, the even higher cost and risk of compressing it into a liquid for long-range tanker shipment. Despite a 1.2-million-mile pipeline network that crisscrosses the United States—carrying gas to population centers from producing areas in the Gulf of Mexico, the Rocky Mountain and southern-tier states, and the enormous fields in Alberta, Canada—not all parts of the country are equally served by gas companies. The pipeline network basically reflects historical gas markets that developed to serve industrial and residential users.

Some utilities, including ones in California, Florida, Louisiana, Oklahoma, and Texas, rely heavily on ample supplies of gas to fire large dual-fuel steam boilers that are often a major part of their electric generating mix. Many utilities throughout the country maintain significant amounts of combustion turbine peaking capacity that often can use either gas or distillate fuel oil; relatively little gas is actually used in these machines, however, because they typically run only a few hundred hours a year.

But markets are changing, resulting in a need for additional gas delivery capability in some areas. Utilities all along the eastern seaboard, from New England to Florida, have the greatest need for near-term generating capacity to meet growing demand, and they are in the vanguard of increasing utility demand for natural gas, according to recent EPRI studies. Yet some parts of these regions have inadequate pipeline capacity to serve substantially expanded markets for natural gas.

Supply and Demand Projections Point Upward

The American gas industry, citing its own North American reserve and resource estimates as well as those of government and other experts, insists there will be plenty of supply and production capacity over the next two decades. It predicts that capacity will rise to more than 22 trillion cubic feet (Tcf) per year by 2000 and to as much as 25 Tcf by 2010. Proved reserves in the lower 48 states are estimated at about 160 Tcf, and estimates of resources that are potentially economically recoverable with present technology range from 900 to 1200 Tcf.

Meanwhile, imports of Canadian gas via pipeline from the richly endowed but depressed fields in Alberta are expected to account for an increasing share of total U.S. gas consumption. The American Gas Association recently projected a possible doubling of Canadian imports, to 2.8 Tcf per year, by 2010.

Several recent analyses of the demand for gas in electricity generation suggest significant growth. The North American Electric Reliability Council projects that over the next decade, gas will fuel more than 40% (or nearly 40,000 MW) of the new utility generating capacity that is installed and will account for over a third of the increased electricity that is generated. (Most of the rest of the new utility capacity will probably be coal-fired.) Cogenerators and independent power producers, who now provide some 6–7% of all the electricity generated in the country, are forecast to build as much new capacity during that time as utilities will, and if the present nonutility generating mix holds, gas could account for 40% or more of that additional capacity.

Government figures on energy consumption indicate that gas accounted for about 9.6% of total electricity generation by all producers in 1990. The Gas Research Institute's widely respected 1992 baseline prediction of energy supply and demand forecasts that this figure will rise to 12.9% by 2000, while coal's share of total generation—reflecting the pressure of increasing environmental costs—will decline from just under 54% to a little over 48%.

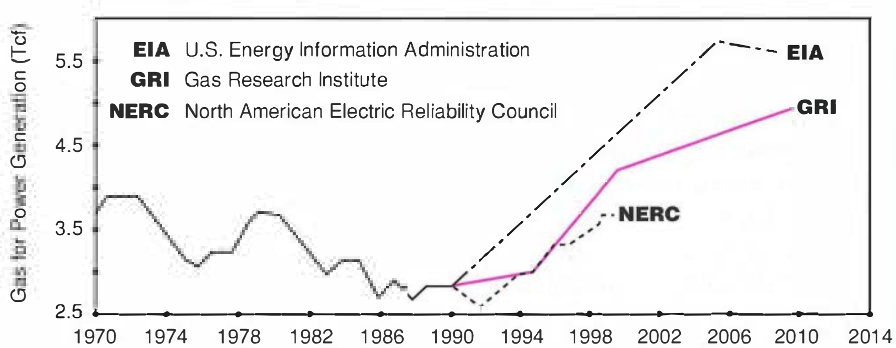
In terms of gas volume, GRI's estimate shows gas demand for electricity generation rising from 2.9 Tcf in 1990 to 4.4 Tcf in 2000. Electricity's share of total gas consumption could reach 20% by 2000, up from today's 15%, according to the GRI projection.

Some analysts are even more bullish on the future for gas in electricity generation than GRI, whose forecasts show utility gas demand largely leveling off after 2000. The New York–based economic consulting firm National Economic Research Associates said in its energy outlook last August that a sustained turnaround in the economy that produces a higher demand for electricity beginning in 1992 could push utility consumption of natural gas to nearly 5 Tcf per year by 2000.

The demand for gas for power generation would continue to rise to as much as 7.4 Tcf per year by 2005, NERA said, "if, as we continue to expect, many utilities are capacity-short by 2000, with too little time to construct new coal-fired capacity, or if environmental constraints further limit the building and siting of coal plants." Nonutility generators could add an additional 2 Tcf per year to gas demand by 2000, NERA said.

Henry Linden, a veteran gas industry expert, past GRI president, and now a professor at the Illinois Institute of Technology, sums up: "There is plenty of natural gas available in the lower 48 states and exportable from Canada at prices that can capture a major share of new intermediate and baseload requirements through combined-cycle systems, plus enough attractively priced gas to meet any conceivable requirements for new straight combustion turbines for meeting peak load, for repowering, and for emissions reduction strategies."

Linden says he continues to believe that "all of the fundamentals are right for adding at least another 50,000 MW of a mix of natural gas–fired baseload, intermediate, and peaking capacity during the next 10 years or so, which would increase annual gas demand by a quite manageable 2–3 Tcf." □



GAS-FIRED GENERATION: THE LAST 20 AND NEXT 20 YEARS **Gas use for electricity generation has declined from its record annual level of nearly 4 trillion cubic feet in the early 1970s to 2.9 trillion cubic feet in 1990. Projections of future use vary widely.**

Major new gas pipeline projects are already under way in Florida, New York, California, and elsewhere. But the complex, protracted federally regulated process of certifying, financing, and building large-scale gas pipelines ensures that they take several times longer to complete than the new gas turbines that would burn the fuel.

In some areas of the country, new emissions limits, rather than the need for new capacity, are the impetus for increased utility gas use. In the upper midwestern and central states, for example, gas is being considered as a possible compliance alternative to adding scrubbers to coal-fired plants under the requirements of the recent amendments to the Clean Air Act. Some utilities have seriously evaluated the cofiring and reburning of natural gas in conjunction with coal combustion.

Utilities in some parts of the country, such as New York and New England, have fired distillate or fuel oil exclusively in their peaking turbines because it was cheap or because large, assured quantities of gas were not available. But the Clean Air Act amendments that mandate sulfur emissions reductions apply to oil-fired as well as coal-fired units, providing yet another incentive to burn gas. However, there will be less flexibility for switching fuels again when the price of gas goes up.

Concerns about the reliability and flexibility of gas supply are an important factor in utilities' reluctance to rely more on gas as a primary combustion fuel. In some areas and among some large users, gas has suffered in the past from a reputation for poor reliability, stemming from the available capacity of existing pipelines.

And the seasonality of gas use as a heating fuel is an important confounding factor. Overall U.S. demand swings from as much as 2.4 trillion cubic feet per month during particularly cold winter months to around 1.2 trillion cubic feet in a typical summer month. Supply reliability under severe winter weather conditions—when demand for gas is greatest—is a serious concern for utilities in Florida, Texas, and elsewhere in the Southwest; these utilities are traditionally among the earliest gas loads to be curtailed when wells freeze off, although pipeline capacity in these areas is sufficient to permit them to use gas in the winter.

Some utilities and experts have also expressed concern about the problems that might result if a large number of new gas-fired combustion turbine–based plants (either simple or combined cycle) were brought on-line in a particular region. When operated in either a load-following (cycling) mode or a peaking mode, the plants' demand for gas can change dramatically in a matter of minutes. The fear is that large pressure drops could occur on some local gas distribution systems or pipelines, causing a deliverability shortfall and shutting off the units' gas. The gas industry maintains that the additional pipeline capacity planned or under construction, together with better coordination between pipelines and power generators, can take care of any specific problems.

Improved planning and coordination between utilities and pipelines will be essential for utilities who opt for greater natural gas use in new turbine-based capacity. One company planning to rely on more gas-fired capacity in the future is New England Electric System. Through much of the 1980s, NEES reduced its heavy dependence on oil by increasing the share of electricity generated by coal-fired units on its system to 50%. But for the next decade, NEES has undertaken a major environmental initiative that involves significantly more gas-fired generation. Beyond the efficiency gains achieved through various demand-side management efforts, the plan includes the conversion of two oil-fired units in Massachusetts and Rhode Island to burn mainly gas. Together these units are expected to require up to 220 million cubic feet of gas per day, according to James Mahoney, a vice president of the NEES subsidiary responsible for fuel procurement.

Mahoney says about half of the projected gas requirement is expected to come from Canada under long-term contracts. The pipeline route involves expansion of the existing TransCanada pipeline system, construction of the new Iroquois pipeline from Ontario through New York and Connecticut, and expansion of the Tennessee and Algonquin pipelines that now serve New England. The other half of NEES's gas requirements will largely come through existing pipelines from the American midcontinent producing regions.

EPRI studies probe the gas market

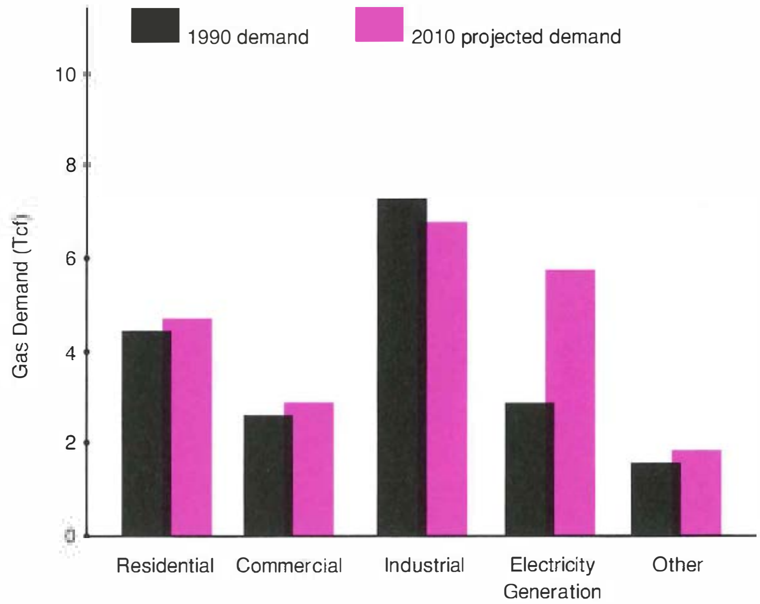
As nearly all observers agree, the gas industry is pinning its hopes on the generation of electricity for a boost over the next decade or more—a boost that will lift both gas demand and gas prices and thus stimulate increased exploration and production. "If it weren't for the use of gas for power generation by electric utilities and other generators, there would be little or no growth in the use of natural gas in the near term," says EPRI's Mueller.

"Apart from power generation, gas is suffering declining market share as a percentage of total energy use, and the absolute quantities of gas use could even go down over the next 5 to 10 years, as conservation programs increase in effectiveness and as electricity continues to gain end-use market share. Over the next 10 to 20 years, the demand curve for natural gas will be pretty flat in virtually everything but electricity generation. The change in gas use in our business could be small or substantial, depending on how gas is used and priced."

Mueller continues: "A focus in the past has been on trying to answer the questions about price and availability of natural gas. Equally important issues are how does gas fit into the generating mix and how does the trade-off between gas and other fuels work at various gas price levels? These questions must be answered in the context of each utility's own generating mix and must be compared against the alternatives. One company's baseload use of gas will be very sensitive to higher gas prices, while another may find that higher gas prices really don't create substantial risks, given the alternatives.

"It is also important to recognize that there are five or six distinct uses for gas by

UTILITIES REPRESENT THE MAJOR GROWTH MARKET FOR GAS Only modest growth in demand for gas is projected in the residential and commercial sectors over the next 20 years, according to recent government projections. And the industrial sector's use of gas is expected to decline over the next two decades, as many processes become electrified. But electricity generation represents a potential major growth market for gas, with demand projected to nearly double from the 1990 level of 2.9 trillion cubic feet. The power generation market, including electric utilities and independent producers, is expected to account for about 94% of the total projected increase in gas demand by 2010.



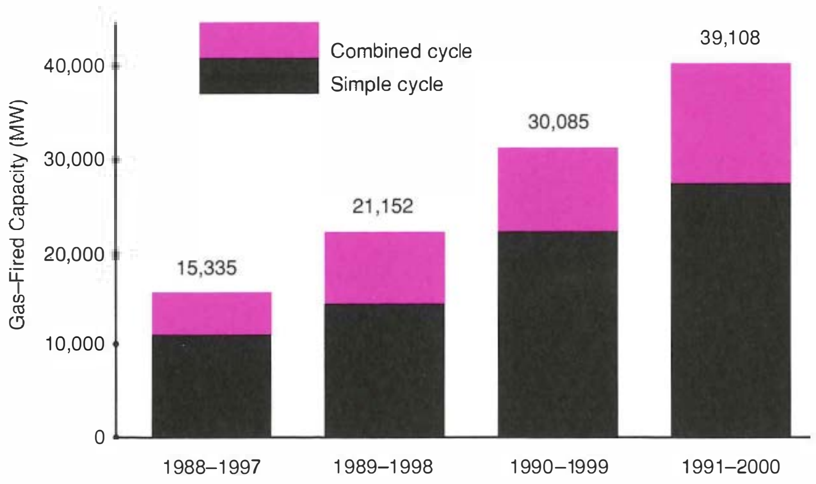
utilities—for peaking or cycling capacity in simple- or combined-cycle combustion turbines, for baseload capacity in steam boilers or in combined-cycle units, for environmental compliance, and for use on the customer side of the meter, where switching between gas and electricity could make more gas available for power generation and environmental compliance. Utilities in various regions are beginning to look at gas this way."

Recent EPRI studies (some of which were cosponsored by the Edison Electric Institute) examined the implications of increased utility use of gas. These studies were conducted independently, with guidance from a spectrum of utility industry advisers. Jensen Associates, of Boston, comprehensively examined the natural gas industry's ability to meet projected requirements for electricity generation through 2000 and addressed the technical issues of gas supply. Jensen also conducted a related study of the potential for increased imports of liquefied natural gas through tanker terminals as a limited but locally useful supply option.

The Washington, D.C., consulting firm of Putnam, Hayes & Bartlett teamed with Energy Ventures Analysis of Arlington, Virginia, in detailing how fuel switching in utility dual-fuel boilers affects the market risks for natural gas. The same contractors separately analyzed the reliability of gas supply during the extreme winter weather of December 1989, when freezes in both producing and consuming areas closed off many wells from production as demand for gas for heating skyrocketed. In another study, the Pace Consultants group surveyed the outlook for the utility market for residual and distillate fuel oil as backup fuels for natural gas.

The current round of EPRI research is focusing on the challenge of coordinating gas supply and power generation operations. "Given the major differences in the operating characteristics of the two systems, the coordination of gas and electricity operations is going to prove to be a major challenge, particularly for the new generation of turbines, whose rapid ramping capability and large size can draw down gas pressures far more rapidly than either steam units or earlier turbines," says Mueller.

"The potential gas requirements of the new generation of turbines exceed the pre-



UTILITY GAS-FIRED CAPACITY PROJECTIONS KEEP RISING Expectations of growth in electric utility gas-fired generating capacity are changing fast. The North American Electric Reliability Council's projections of new utility gas-fired capacity as a percentage of total planned utility capacity have risen from 20% to 44% over the last four years. Simple-cycle turbines are expected to account for most of the increase in utility gas-fired capacity.

A new generation of more powerful, more reliable, and more efficient combustion turbines has begun entering service in recent years, as represented by General Electric's new Frame 7F models. In a combined-cycle configuration with two or more units linked to an exhaust heat recovery steam generator and a steam turbine, the new gas turbine plants can operate at an unprecedented efficiency of 50% or more.

These units are also capable of firing synthetic gas made from coal in one of several advanced gasification technologies now being offered commercially by Texaco, Shell, Dow Chemical, and other developers. An integrated, 100-MW coal gasification–combined-cycle power plant using Texaco's gasification technology was demonstrated at the Cool Water project during the 1980s in southern California. The capability for phased construction of such integrated gasification–combined-cycle (IGCC) plants—beginning with the combustion turbines, later adding the steam generator and the steam turbine, and still later building the coal gasification unit nearby—has long been investigated by EPRI and a number of utilities.

Phased IGCC is seen as a modular approach to incremental capacity additions that, over a number of years, could transform low-capital-cost ($400/kW), short-installation-time (one to two years), but high-operating-cost peaking turbines into more efficient and economical intermediate and (eventually) baseload generating units.

"The commercial availability of IGCC technology is going to be a key factor in the decision of many utilities and even independent power producers to choose gas-fired plants for much of the new capacity likely to come on-line during the 1990s, because that technology represents an ultimate cap on the price of gas," says Charles Goff, president and chief operating officer of Destec Energy, Inc., an independent power producer and subsidiary of Dow Chemical that builds, owns, and operates gas-fired cogeneration plants and also markets IGCC power plant technology. (Destec and PSI Energy recently announced a joint venture under the Department of Energy's Clean Coal Technology Demonstration Program to convert a coal-fired generating plant in Indiana into a 265-MW IGCC unit.)

"If IGCC is factored into the planning, a utility can commit to adding gas-fired capacity and can later build a coal gasification unit to replace natural gas with coal in an environmentally clean manner that will exceed the post-2000 Clean Air Act standards," says Goff.

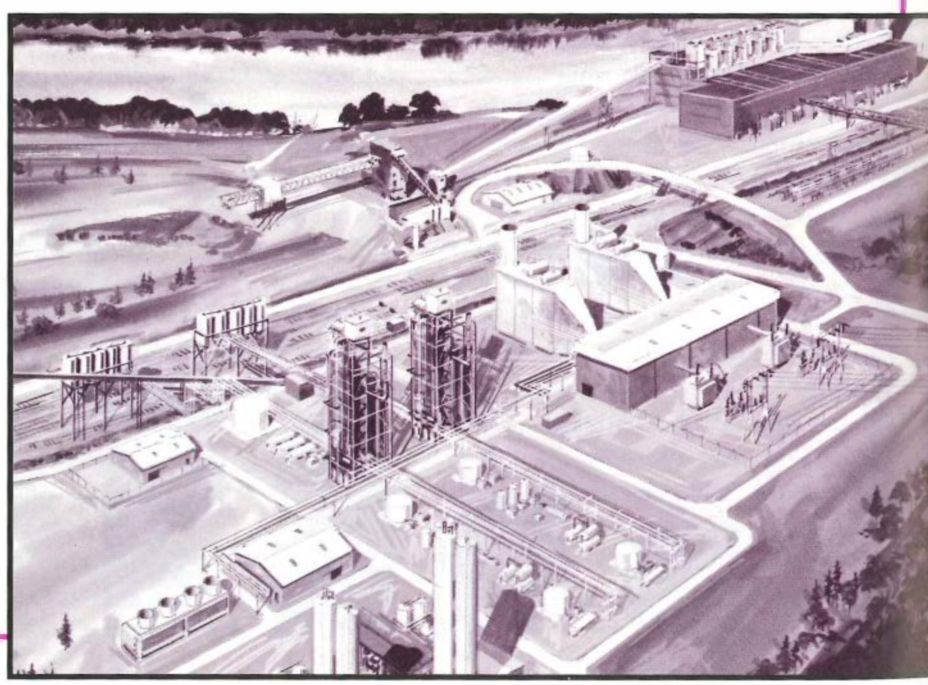
"There are risks associated with relying more heavily on gas, simply because of the future price uncertainty," says Jim Fortune of EPRI's Integrated Energy Systems Division. "That's one reason EPRI has stressed planning for phased construction of IGCC technology. This is a way to minimize the risk of gas-fired generation by intelligently designing these new power plants to enable the later addition of coal gasification."

Studies by EPRI and others have estimated the levelized price at which the additional investment in IGCC is competitive with gas to be between $4 and $6 per million Btu. Gas has been selling for as little as $1.10 per million Btu (one thousand cubic feet is equivalent to a million Btu) in recent months, although in recent years it has been as high as $3 per million Btu.

"We're seeing a number of utilities—including many who have experience with gas but who have been reluctant to plan long-term capacity projects that rely on more gas—making the hurdle over that decision because of the commercial readiness of clean coal gasification as the ultimate backstop and a hedge on the ultimate price and availability of natural gas," says Goff. □

IGCC: An Ultimate Cap on Gas Prices

Destec Energy and PSI Energy plan to convert a coal-fired Indiana generating plant into an integrated gasification–combined-cycle unit.



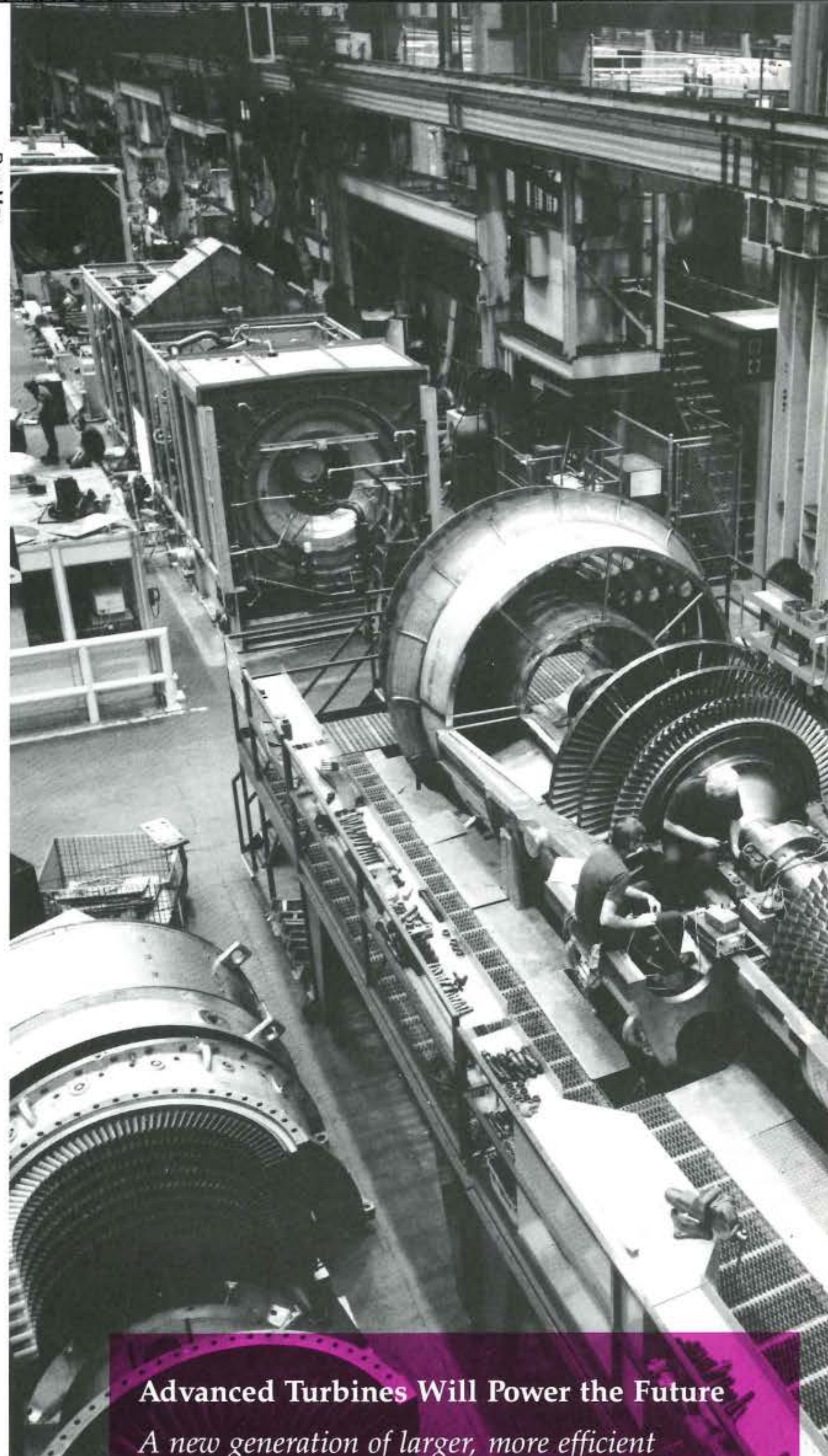
vious experience of most pipelines in meeting power generation loads. Generating plants based on the new turbines also require supply pressures and operating characteristics that are different from those of typical local gas distribution systems.

"Future gas generation is going to require tailored, carefully designed service if units are to operate reliably. Gas suppliers and pipelines are going to have to offer utilities something other than 'plain vanilla' service, and the utilities are going to have to site and design these units and their operations carefully, with close coordination with gas suppliers."

Mueller says that what makes sense or works effectively for one utility won't necessarily hold up if every utility in a region tries to do the same thing. "For that reason, we have begun working with individual utilities and groups of utilities to better understand what their gas planning requirements and gas opportunities and risks really are."

One implication, Mueller explains, is that as utilities grow more reliant on gas, the value of storing large quantities underground in depleted production fields or other suitable geologic formations will increase dramatically in order to serve both operational and long-term economic needs. "There are a lot of geologic opportunities for storing gas, but most of them unfortunately are not near the eastern metropolitan areas that are looking to gas for much of their future generation and that are constrained by the availability of pipeline capacity."

In cooperation with gas companies, utilities in Texas have developed effective procedures to coordinate and communicate on an operational level so as to minimize disruptions in gas supply availability; other utilities may soon be learning a lesson from them. EPRI is now funding additional studies of the implications of future gas demand, including an analysis of the coordination problem and how utilities in such states as Texas and Florida have addressed it. Research is also under way to quantify in greater detail the risk associated with po-



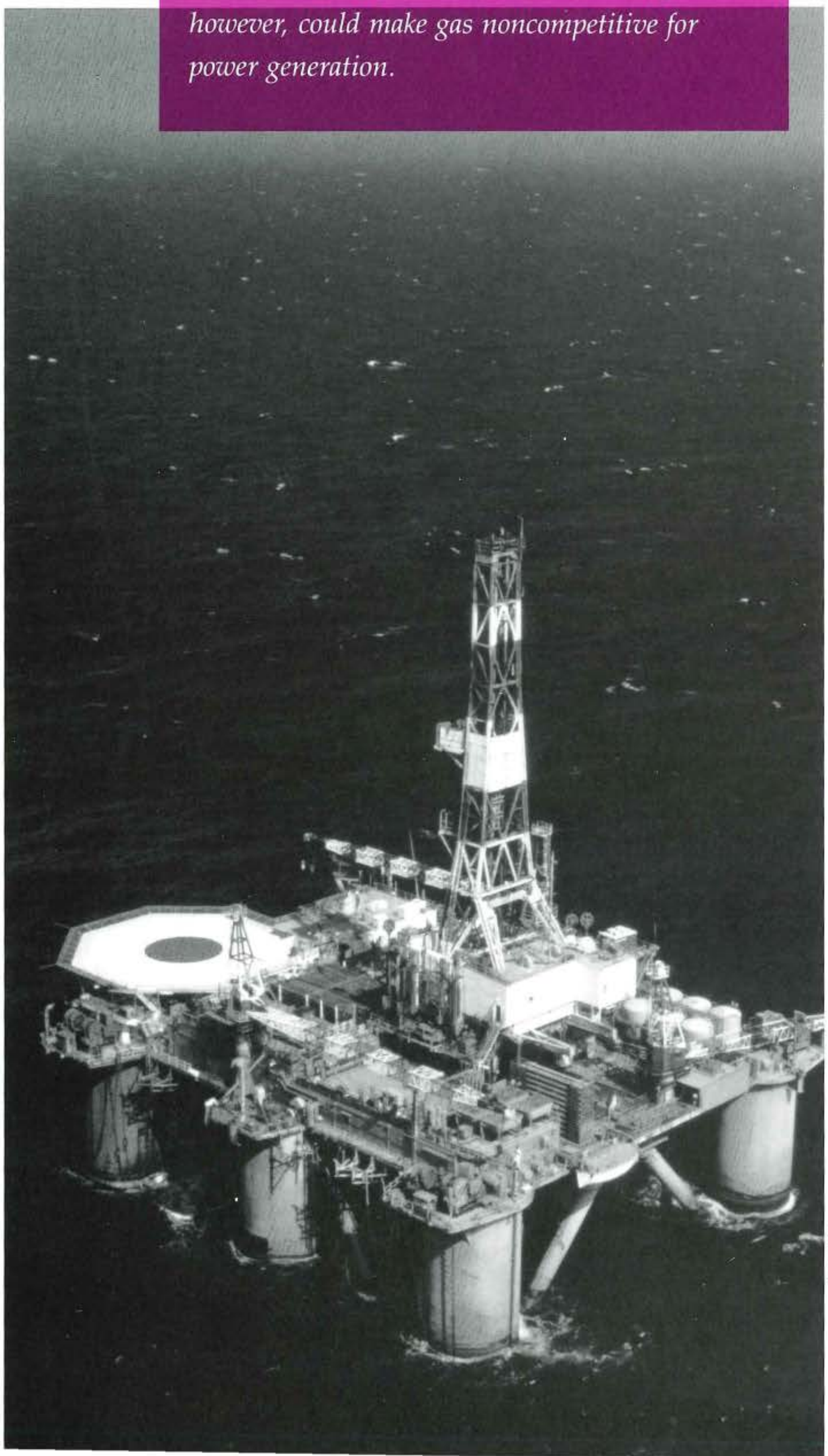
Ron May

Advanced Turbines Will Power the Future

A new generation of larger, more efficient combustion turbines will be at the heart of most new gas-fired generating capacity added by utilities and other producers in the 1990s. In terms of operating characteristics and demand for gas, these turbines differ fundamentally from the steam boilers that now account for most utility use of gas.

Keeping Upstream Resources Flowing

As long as current market prices for natural gas remain below the cost of replacing reserves, gas producers have little incentive to invest in the upstream exploration and drilling that are necessary to sustain significant future growth in demand for gas. Prices that are too high, however, could make gas noncompetitive for power generation.



Ron May

tential gas price increases in the years ahead.

"Very soon, we hope to quantify for utilities the relative risks associated with an increased use of gas for electricity generation," says Michael Gluckman, director of EPRI's Integrated Energy Systems Division. "We want to identify ways in which utilities can make their capacity and fuel planning more flexible, so they can minimize the risk of service disruption associated with the potential for gas supply problems in the future."

Gluckman notes that electric and gas utilities have traditionally defined reliability very differently, a situation that might have to change as they become more interdependent. "Electric utilities ensure reliability by providing capacity reserve margins, but when gas companies have supply shortages or more demand than pipeline capacity, they have typically curtailed or cut off deliveries to traditionally interruptible customers, such as utilities. If utilities are going to be using a lot more gas, an important question is whether they should build storage facilities at power plant sites or somewhere else or should site their power plants in other locations."

Contracting for future supply

In the final analysis, an increased use of gas by the utility industry will depend on the ability of gas producers and utility companies to forge supply contracts acceptable to both parties. The sticking point for many utilities is the need for economical long-term supply contracts. CMS Energy (together with its Consumers Power utility subsidiary in Michigan) is one major gas-using utility that has signed many such contracts. In the 1980s, CMS Energy converted its unfinished Midland nuclear unit into a 1370-MW gas-fired combined-cycle cogeneration plant that uses about 75 billion cubic feet of gas a year. The company's chairman and CEO, William McCormick, is the immediate past chairman of the American Gas Association.

"We have under long-term supply contracts about 80% of the gas that will be needed over the first 12 to 15 years of the Midland plant's operation, and we even have some contracts that run up to 20 years," says McCormick. "I recognize that gas supply security is a concern in the minds of some utilities, but I believe that's because they are unfamiliar with relying much on gas-fired generation."

But other utilities have found that long-term supply contracts carry substantial premiums over present market prices. NEES, which believes long-term contracts are not essential, nevertheless went to Canadian suppliers to buy fuel at the going market price for its new gas-fired plants. NEES's Mahoney says that the utility tried to obtain long-term contracts from U.S. suppliers but found them unwilling to offer terms similar to those available from Canadian producers, except at a substantial premium. Mahoney feels that such a premium is not justified "in view of the apparent adequacy of North American gas reserves."

Jim Fortune, who heads engineering and economic evaluations in EPRI's Integrated Energy Systems Division, sheds some light on why gas suppliers are hedging their bets on the long term: "Although there may be adequate resources in the ground, I believe that the price required to get the gas out of the ground is going to go higher." Jeremy Platt, a resource geologist and EPRI project manager, agrees: "As long as gas prices remain low, there is reason for concern about the implications for the upstream, exploration side and for long-term deliverability in the gas production industry. With prices in the range of $1 to $2 per thousand cubic feet, a lot of domestic gas companies are reducing their operating staffs, and hardly anyone is drilling new holes in the most promising areas in the Gulf of Mexico. It will take higher prices to bring a lot of the lost domestic exploration and production back. The financial attractiveness of looking for more gas to supply increased needs in the future is just not there at current prices."

Kenneth Lay, chairman and CEO of Houston-based Enron Corp.—the world's largest integrated natural gas company—agrees that spot prices are below production replacement costs and that they must move somewhat higher to ensure long-term supplies. "We have sold a lot of gas under long-term contract at prices that are above replacement costs, but we are still talking about long-term gas prices that will remain at or below fuel oil prices for years to come. Spot gas prices recently have been moving up a little, which is in the right direction and is what is needed to ensure the long-term viability of the business and the exploration and drilling required to continue replacing production."

Lay notes that while "drilling activity is down substantially from just a few years ago, our company and the gas industry are now much more productive, even with fewer wells being drilled, because of the continuing advances in technology—from seismic techniques in finding new gas to better drilling bits, better drilling methods, and higher well completion rates."

According to Henry Linden, the former president of the Gas Research Institute who now serves on EPRI's Advisory Council, at least some of the solution to gas pricing concerns is out of the hands of both electric utilities and the gas industry. Linden is an outspoken critic of various regulatory barriers that "don't allow the concerned parties to pursue their apparent self-interest." Referring to proposed new Federal Energy Regulatory Commission regulations to unbundle pipeline services, Linden says, "Unfortunately, they would practically eliminate the pipelines as supply aggregators and would further impede the availability of reliable and predictably priced long-term gas supplies, which is the biggest barrier." Other proposed FERC regulations covering pipeline construction were recently cited by a group of gas companies as the principal factor in their cancellation of a major new pipeline that was to bring over a billion cubic feet of gas per day from new wells in Mobile Bay into the burgeoning Florida gas market.

The gas supply industry may need to make substantial changes in its modes of operation if it is to win the electric utility market. Enron took such a step three years ago with its gas bank production pooling program, designed to reduce the risk to large industrial and utility users of future gas price hikes. Since then, the giant gas firm has signed up more than 60 other independent producers and over 80 large customers on long-term contracts—although at a premium price compared with current spot prices. "We are signing contracts today for as long as 15 years that guarantee the supply and price, with over $10 billion in assets standing behind that guarantee," says Enron's Lay.

Concludes EPRI's Howard Mueller: "Electricity generation is really the only major growth opportunity that the gas industry has. But in order to serve the new generation of turbine-based capacity that we are adding, gas companies—suppliers, pipelines, and distribution companies alike—are going to have to provide a type of service that is designed to meet electric utilities' needs. That means a different class of service from that of the past.

"The type of service offered has to recognize the operating characteristics of these units, and the pricing has to reflect the competing types of generation available to the utility in its own generation mix and region. Gas use has terrific potential to grow in our future, but both industries will have to work together to fully realize that potential." ■

Further reading

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This article was written by Taylor Moore. Background information was provided by Jim Fortune, Michael Gluckman, Howard Mueller, and Jeremy Platt, Integrated Energy Systems Division.

WIN

THE SPEED AND IMPORTANCE OF TECHNOLOGICAL CHANGE IN THE MODERN WORLD have substantially changed the demands on research and development over the past 20 years. Discovering new ways of applying cutting-edge science to the technological needs of industry has never been more important. And at the other end of the R&D pipeline, delivering practical results to the marketplace in the form of useful products is key to being able to capitalize on development efforts.

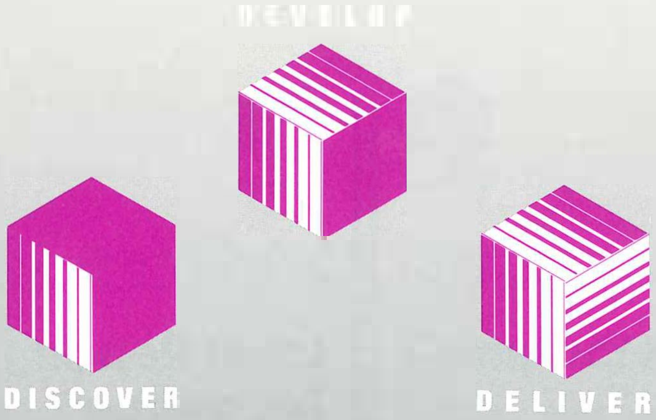
While these crucial front- and back-end elements of the R&D process have always been implicit in EPRI's work, the pursuit of innovative basic research and the successful transfer of research results are now explicitly set forth in the Institute's mission statement: to *discover*, *develop*, and *deliver* advances in science and technology for the benefit of member utilities, their customers, and society.

The new emphases in this revised mission reflect a change in corporate culture at EPRI. And in support of that change, the Institute has inaugurated a series of Discovery, Development, and Delivery Recognition Awards for exceptional contributions by individual staff in each of the three D categories. The 1991 winners share awards for three projects in the discovery category, four in development, and four in delivery.

The award recipients were honored at a dinner in Palo Alto on November 9, 1991. In his remarks on that occasion, Senior Vice President Kurt Yeager stressed the importance of cultural change: "To ensure EPRI's success in the nineties, it has become necessary to increase Institute activities in the discovery of new technology as well as its delivery. Early in 1991, we changed our corporate mission statement to reflect these facts. The Discovery, Development, and Delivery Awards, which we are presenting here tonight, are an expression of our commitment to these ideals."

"The new mission statement and the awards that have grown out of it reflect an effort on the part of EPRI to be more market-driven," says Karl Stahlkopf, chairman of the awards selection committee. "We have an obligation to ensure that the technology developed here is used, and is found useful, by our members. That means more resources must be devoted to long-range, discovery-type research that can help American industry compete better on a global basis. Also, if EPRI technology is to achieve greater penetration of the electric power market, we must play a more active role in delivering technology to member utilities."

This year's awards in the discovery cate-



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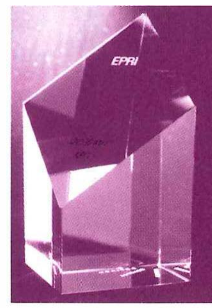


THE STORY IN BRIEF

Keying on the emphases of its mission statement, EPRI has initiated annual awards that recognize outstanding achievement by its staff in furthering the discovery, development, and delivery of advancements in science and technology. The award-winning projects represent some of the Institute's most innovative and successful efforts to serve the utility industry, its customers, and society at large.

gory reflect pioneering efforts to apply new science and new technological approaches in diverse fields. Awards for development involve technologies that are likely to produce major near-term economic benefits for electric utilities. The delivery awards illustrate how EPRI technology has already been put to work by U.S. utilities. An additional, special award was made to Senior Vice President Ric Rudman for developing the concept of tailored collaboration, which will help EPRI's research be more responsive to individual utilities' system needs.

"Tonight's awards represent the first in an annual series to honor the best of the contributions of EPRI's staff in carrying out our mission," President Richard Balzhiser said at the presentation. "Through their accomplishments, tonight's winners are ensuring a bright future not only for themselves but for EPRI as well."

DISCOVER

Robert Goldstein

Genetic Ecology

Genetic ecology is the study of how environmental factors affect the abundance and function of genes among natural populations of microorganisms. This knowledge may eventually provide less expensive ways to clean up soil and water contaminated by toxic materials. Robert Goldstein is recognized for helping to create this emerging field of science and for naming it.

The field of genetics has been developing molecular techniques to understand environmental processes at the genetic level, and Goldstein recognized that this understanding could be used to manage problems of concern to the utility industry. Through EPRI-sponsored work he has directed, genetic ecology is now being used to determine how the decomposition and transformation of certain chemicals by naturally occurring microorganisms is controlled at the genetic level. On the basis of this knowledge, field tests will soon be undertaken to determine whether such natural processes can be stimulated for the bioremediation of toxic waste sites.

"Our knowledge of molecular genetics is growing exponentially," Goldstein says. "It's providing extremely powerful techniques that can potentially be more effective for cleaning up wastes at lower cost."

DISCOVER

Mel Lapides

Laser Repair Technique

Mel Lapides discovered how to use lasers and fiber optics to assess material properties and look for defects in otherwise inaccessible areas of a power plant. In this technique, pulses of laser light travel along optical fibers inserted into remote and even hostile environments, such as steam generator tubes in a nuclear facility. Returning pulses contain information about the chemical and physical properties of the metallic materials and enable an operator to detect and diagnose microscopic defects, such as cracks in a metal tube. In some cases, defects can also be repaired by sending stronger pulses through the fibers.

"Think of it as a microscopic Roto Rooter," Lapides suggests. "You can inspect an interior surface as with a microscope, volatilize part of the surface and read its chemical composition, or generate an ultrasound pulse that lets you look at what's going on beneath the surface. Each of these functions is important for carrying out inspections inside critical power plant components.

"Another important capability we're exploring is to use the laser light emerging from the tip as a drill to penetrate an inch or so into the metal, while reading data from the vapor created. This technique provides composition gradients through a material that you couldn't ordinarily get without removing a sample. Thus you can explore conditions deep within the walls of a piece of equipment without having to shut down the plant or create problems by excising material. The time saved can be considerable; for example, with the optical device we can analyze in seconds some material that would take hours to sample physically."

The use of the device is still in the proof-of-feasibility stage. EPRI is currently working with utilities to validate various applications in power plants. In addition, a cooperative agreement has been signed with the National Institute of Standards and Technology to explore nonutility uses.

DISCOVER

Ramsay Chang

Compact Hybrid Particulate Collector

Ramsay Chang recently received a patent for inventing the Compact Hybrid Particulate Collector (COHPAC), a device for restoring or upgrading the performance of an electrostatic precipitator (ESP). COHPAC consists of a pulse-jet baghouse that is placed behind or within an existing ESP and operated at more than four times the filtration velocity of a conventional baghouse. Because of this higher velocity, the size and cost of the baghouse can be reduced proportionately. With this configuration, emissions can be kept below the New Source Performance Standard for a very low price—the addition of COHPAC costs as little as $10/kW.

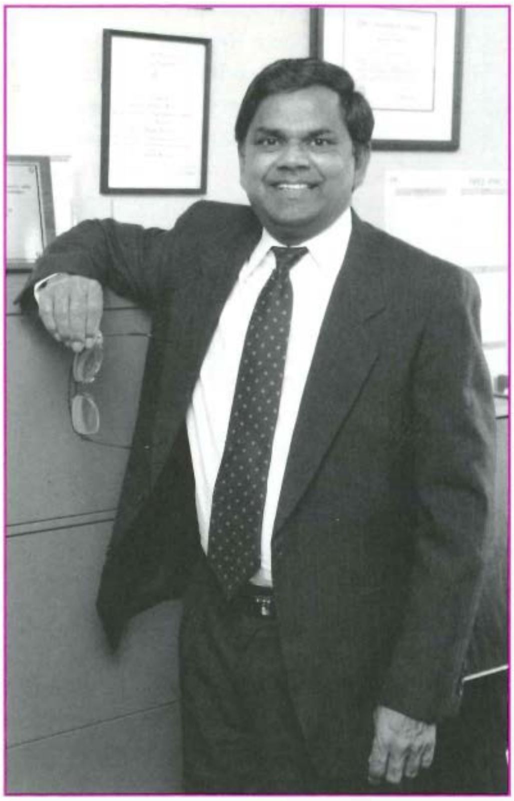
When Chang first conceived the idea for COHPAC, he obtained exploratory research funding for a proof-of-concept test at the High-Sulfur Test Center. Since then, COHPAC has been demonstrated in two configurations on a 1-MW pilot plant at Texas Utilities' Big Brown power station. Chang was the lead technical contributor during early tests of COHPAC and is now supporting design work on a 165-MW demonstration system, also sited at Big Brown.

"Because of recent amendments to the Clean Air Act, many utilities are switching to low-sulfur coal," Chang explains. "But the performance of electrostatic precipitators may be degraded by such changes, and in many cases it's less expensive to add a small COHPAC unit than to enlarge the precipitator. In addition, COHPAC has the potential for removing toxic elements from the flue gas stream, so it may become even more important in helping utilities meet future regulations dealing with toxic emissions." EPRI estimates that the immediate potential market for COHPAC could be as high as 80,000 MW; if this potential is reached, it could save the industry as much as $1 billion.

DEVELOP

Neal Balu

Training Simulator for Energy Control Center Operators



As bulk power systems become more complex, more powerful tools are needed to provide training simulation for system operators. Specifically, computerized simulators must be able to accurately model energy control system functions under such extreme conditions as voltage collapse, large frequency disturbances, system breakup, blackouts, and system restoration. EPRI's Operator Training Simulator (OTS), developed over an eight-year period under the direction of Neal Balu, provides these and other functions still not available on other simulators.

The initial version of OTS was delivered as a commercial-grade system at Philadelphia Electric, the host utility. The development of the simulator involved cost sharing by Philadelphia Electric and the prime contractor, Empros International. To date, more than a dozen utilities have placed commercial orders for OTS, and an overwhelming majority of utilities now specify inclusion of the EPRI simulator when ordering a new energy management system.

Currently, Balu is directing efforts to convert the OTS software to a UNIX computer operating system, which will result in a highly standardized package that can run on low-cost workstations. The UNIX version will also be capable of linking up to eight energy management system computers in a network.

"Previously, simulators were used primarily by large and medium-sized utilities, because they were designed to run on big, expensive mainframes," Balu says. "By putting OTS on a UNIX workstation, we can also reach smaller utilities, such as co-ops and munis, giving them access to a state-of-the-art tool on affordable hardware. We believe the potential market for OTS is about 75 utilities."

DEVELOP

Lawrence O'Co

Electric G-Van

Electric vehicles (EVs) can help alleviate many of the air quality and noise problems that plague urban areas, while also reducing U.S. dependence on foreign oil and improving utility load profiles. Because

most EVs will be charged overnight with off-peak power, their increased use will help lower the average cost of electricity for all utility customers. Despite this potential, however, EVs have been slow to enter commercial production.

nell

Most of all, the EV concept has needed a "product champion" to push commercialization through the many technological, manufacturing, and distribution hurdles accompanying such a far-reaching change. Such championing has largely been provided by EPRI as an institution and Lawrence O'Connell as an individual. Working closely with the automobile industry, battery manufacturers, and utilities, O'Connell helped advance EV technology and catalyze its first commercial production. The result is the Electric G-Van, the first modern American-made EV to be produced in volume and distributed through a nationwide network.

"The most important aspect of EPRI's work in this area was to show that EVs could be commercially viable," says O'Connell. "Specifically, we demonstrated that they could fill an important niche market—urban delivery vehicles. I believe this niche market will persist on its own merits. In addition, new state regulations requiring zero-emission vehicles by the turn of the century will greatly enlarge the EV market. Utilities can play a major role in the emergence of this market, and our experience has been that the more they gain experience with EVs, the more interested they become."

The G-Van is based on technology proven in Britain and enhanced to give it a competitive edge in the U.S. market for commercial van fleets. The van has a range of approximately 60 miles in city driving, with a top speed of about 52 miles per hour, and will be available in both cargo van and passenger wagon models.

DEVELOP

Joseph Naser

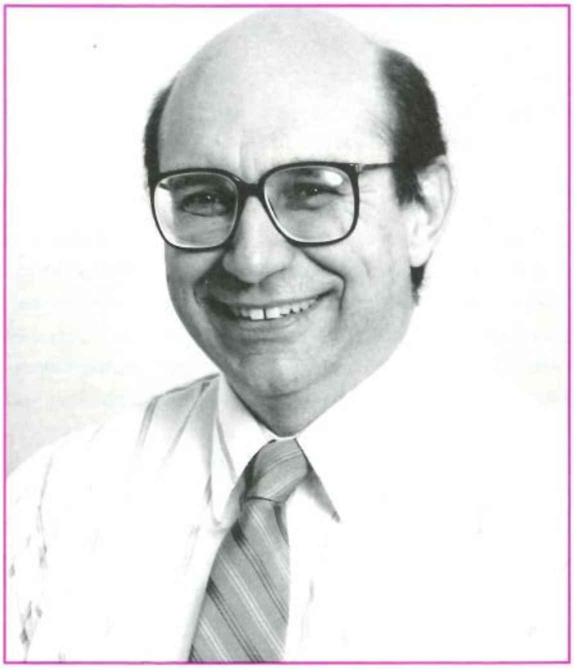
Expert Systems for Refueling of Nuclear Reactors

When a nuclear reactor is refueled, some old fuel is removed and some partially spent fuel is repositioned in the reactor core. This operation involves a complicated shuffling of fuel elements, which must be planned in a way that not only minimizes the time and crane movements required but also takes into account how individual fuel elements affect the criticality of the reactor system itself.

Joseph Naser developed an expert system that improves the productivity of refueling. Having such a system available, he explains, can help nuclear utilities in several ways. "First, during the planning process, this system—if used in the fully automatic mode—can produce a refueling plan in about 20 minutes, compared with the more than three man-weeks of work when using conventional methods. Thus, a utility can afford to map out several different plans to see which one would save the most time during the refueling outage.

"In addition, utilities are finding other advantages. Problems can occur during an outage, for example, when a bad fuel element is discovered. Our expert system is able to modify the refueling plan in minutes and help bring the plant back on-line without losing another day or so while the plan is revised manually. Some utilities with boiling water reactors are also finding that the system can help them do in-core refueling rather than completely unloading and reloading the fuel."

Although Naser is being recognized for the development of the expert system, his work actually spanned the discovery and delivery steps as well. He personally invented a prototype system to show feasibility, then worked with ABB Combustion Engineering to develop a commercial version. He worked closely with Florida Power & Light on the first utility demonstration (for a pressurized water reactor) and is currently working with Philadelphia Electric on the first BWR demonstration.



DEVELOP

Harshad Mehta

Advanced MOS-Controlled Thyristor

Silicon thyristor technology promises to transform the nation's high-voltage transmission system in much the same way that low-power transistors have revolutionized consumer products and communications networks. The replacement of conventional electromechanical switches with faster, more reliable solid-state devices will eliminate increasingly troublesome bottlenecks on transmission systems.

Harshad Mehta's work focused on producing a new type of thyristor that would be best suited for this application. Using metal oxide semiconductor (MOS) technology, the advanced MOS-controlled thyristor, or MCT, combines the high-power-switching capability of previous thyristors with the built-in "smart" functions of integrated circuits. MCT technology is particularly well suited for efficient and fast switching operations in power electronic equipment for a number of utility applications.

For utilities, MCT offers significant potential for energy savings. "This device is an order of magnitude better in performance than any other similar technology—with reduced electrical losses, greater switching speeds, and reduced harmonics," says Mehta. But there are broader implications as well: "This development gives the United States a technological lead in a key component area of power electronics, an advantage that will be greatly magnified at the system level."

During the past year, Mehta has been coordinating EPRI's research efforts with those of the Department of Defense to develop a 2500-volt, 1000-ampere MCT module that can be used in static VAR compensators and transmission line circuit breakers. Through collaboration with government agencies, Mehta leveraged EPRI's investment by at least an order of magnitude. Currently, he is negotiating a manufacturing license with the Harris Corporation, which intends to commercialize the MCT technology.

DELIVER

Howard Mueller

Self-sustaining Fuel

"When we began work on utility fuel management, there were no strategic analytical tools available in a number of major areas," says Howard Mueller. "Now, through EPRI leadership, a nearly complete capability has been put in place and has begun to have substantial impact on the industry."

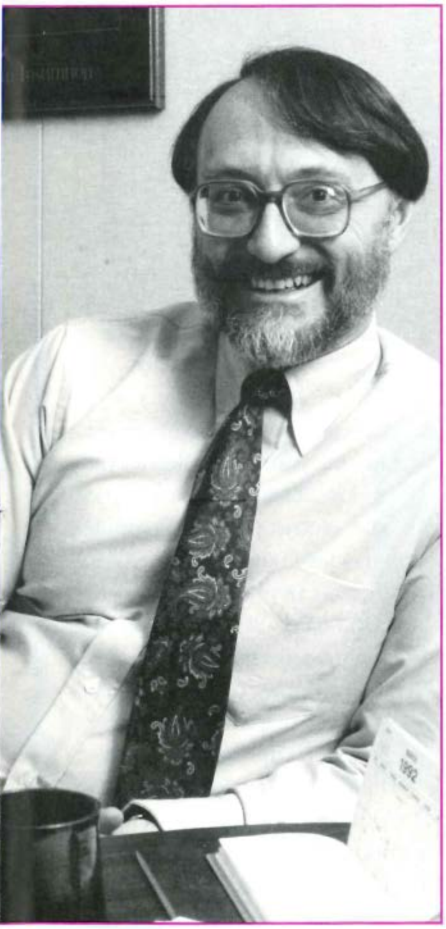
Mueller has worked through EPRI's Utility Planning Methods Center (UPMC) to develop and deliver fuel planning models that have been widely adopted by electric utilities. This software consists of databases and models that help utilities with both their short-term and their long-term fuel planning.

Working through a utility users group, Mueller developed the concept of an EPRI extended service contract for UPMC software. This arrangement guarantees maintenance of the fuel planning models, as well as user support throughout the useful lifetime of the UPMC software products, and ensures that

lanning Models

those products can be sustained over time.

"The key to success in delivery is to work closely with our utility members from the outset of product development," Mueller says. "They must be involved in the initial design and development and then be provided quality service for the finished product—including training, software maintenance, and technical support."



DELIVER

Robert Moser

FGDPRISM Scrubber Design Model

FGDPRISM, a computer model for improving flue gas desulfurization systems, has provided a vehicle for commercializing major results from EPRI's extensive research on sulfur dioxide controls. Having evolved over a 10-year period, the model is currently being used to evaluate designs of stack gas scrubbers mandated by the recent amendments to the Clean Air Act. Robert Moser directed the development and commercialization of FGDPRISM.

A critical element of the delivery process was providing copyright protection to ensure that EPRI member utilities would get the benefit of their investment while discouraging illegal use. "We decided it would be impossible to get adequate protection against copying of the software, so we added a hardware key," Moser recalls. "To run the program, a user has to install a special cable connector—which has some software built into it—on the back of the computer. Each time the program is run, a counter in the connector deducts points from the total permitted. When the limit is reached, the user has to have the counter replenished.

"This arrangement facilitates different kinds of licensing. A user can either contract for pay-as-you-go privileges or get a license for unlimited use. Also, someone could copy the program all they wanted but would not be able to use it, since the connector's built-in software enables FGDPRISM to function. This hardware key thus offers a more secure alternative to copyright protection and provides a way of knowing how much the program is being used."

The need for such precautions is reflected by the considerable popularity of the program: more than $500,000 in license fees was collected during the first eight months of release. Requests for licenses have come from process suppliers, international utilities, and consulting firms. Almost all EPRI members that are planning or purchasing scrubbers have used FGDPRISM. The program can help utilities reduce costs and improve reliability by about 10–15% when retrofitting scrubbers. It has also been used extensively to troubleshoot and improve the performance of existing scrubbers.

DELIVER

Vito Longo Barbara Braithwaite William Shula Bruce Rytkonen

National Lightning Detection Network

Vito Longo, Bruce Rytkonen, Barbara Braithwaite

Lightning causes up to $100 million in damage to electric utility facilities every year, and having real-time information on lightning activity in their territories can enable utilities to deploy repair crews more readily. The National Lightning Detection Network was begun about eight years ago. Since the NLDN's inception, its value has been rapidly recognized by the airline industry and others. Today the network has about 100 subscribers, most of which are electric utilities. Several Strategic Air Command bases and one commercial airline also subscribe, and other airlines are negotiating subscriptions.

Because of this success, the commercialization of the NLDN has proceeded more rapidly than had been expected. The award recipients were all involved in the transfer of the NLDN from the State University of New York at Albany, the original research contractor, to GeoMet Data Services, Inc. (GDS), the current commercializer. GDS is a division of Dynatech, a Burlington, Massachusetts, manufacturer of high-tech equipment, and the commercialization negotiations with this company were some of the most complex ever handled by the Institute.

"What we're seeing among utility subscribers is that they are able to respond more quickly and effectively to damage caused by storms," says project manager Vito Longo. "Some interesting secondary effects are also being reported. For example, one utility was able to reduce the time it was on 'storm watch' with very expensive standby generators running in case lightning struck a major feeder line. Another utility used the network to tell when lightning was getting close to a critical transmission line from its nuclear power plant."

The NLDN consists of about 120 magnetic direction finders throughout the United States that transmit directional information about each lightning strike in their vicinity via a satellite link. This information is forwarded to the central network computer, which pinpoints the location of the strike on the basis of signals from multiple direction finders. In addition to providing real-time information on the movement of potentially destructive storms, the network is being used to compile statistical information on lightning activity that utilities can use in siting new facilities. The U.S. Weather Service is also considering how it could use the NLDN to improve its weather forecasts.

DELIVER

Robert Schainker Ben Mehta Robert Pollak James Goodson

Compressed-Air Energy Storage

The compressed-air energy storage (or CAES) system accepted by Alabama Electric Cooperative (AEC) on June 1, 1991, represents the first completely new commercially viable generation option delivered in the U.S. utility industry in three decades. Constructed by dissolving a huge air storage cavern out of a salt dome near McIntosh, Alabama, the CAES plant has a 110-MW capacity and can run 26 hours on a full charge of compressed air. The plant was built on a fixed-price basis for $51 million, representing a capital cost of $464/kW.

"Storage in general will have an increasingly important role in the electric power industry," Robert Schainker says. "We are fortunate that CAES is becoming a commercially viable storage option at this time, because nearly three-quarters of the United States has geologic formations that could potentially be used for CAES. Some 12–15 utilities are now conducting studies related to the economics or geology of CAES in their service territories."

The delivery effort for which this team is honored was particularly challenging for several reasons: the project involved technology unfamiliar to most utilities, the use of new planning and evaluation methods, a utility investment in a new technology, and the need to establish vendor consortia. Bringing about successful technology transfer required catalyzing the formation of vendor teams to bid on the project and promoting close work between EPRI staff and the host utility to oversee construction.

Robert Schainker was program manager; Robert Pollak, project manager; Ben Mehta, plant geology manager; and James Goodson, on-site field engineer.

Robert Schainker, Ben Mehta, Robert Pollak

This article was written by John Douglas, science writer, from interviews with the award winners and with Karl Stahlkopf, chairman of the awards selection committee.

Connecting With Ru

Линии высоковольтной передачи

DEEP IN THE MIDST OF THE FRIGID SIBERIAN TUNDRA, where temperatures have plunged as low as –58°F, the world's highest-voltage transmission line goes about its business of transporting electricity to be used by Russian factories, homes, and government buildings more than 2000 miles away.

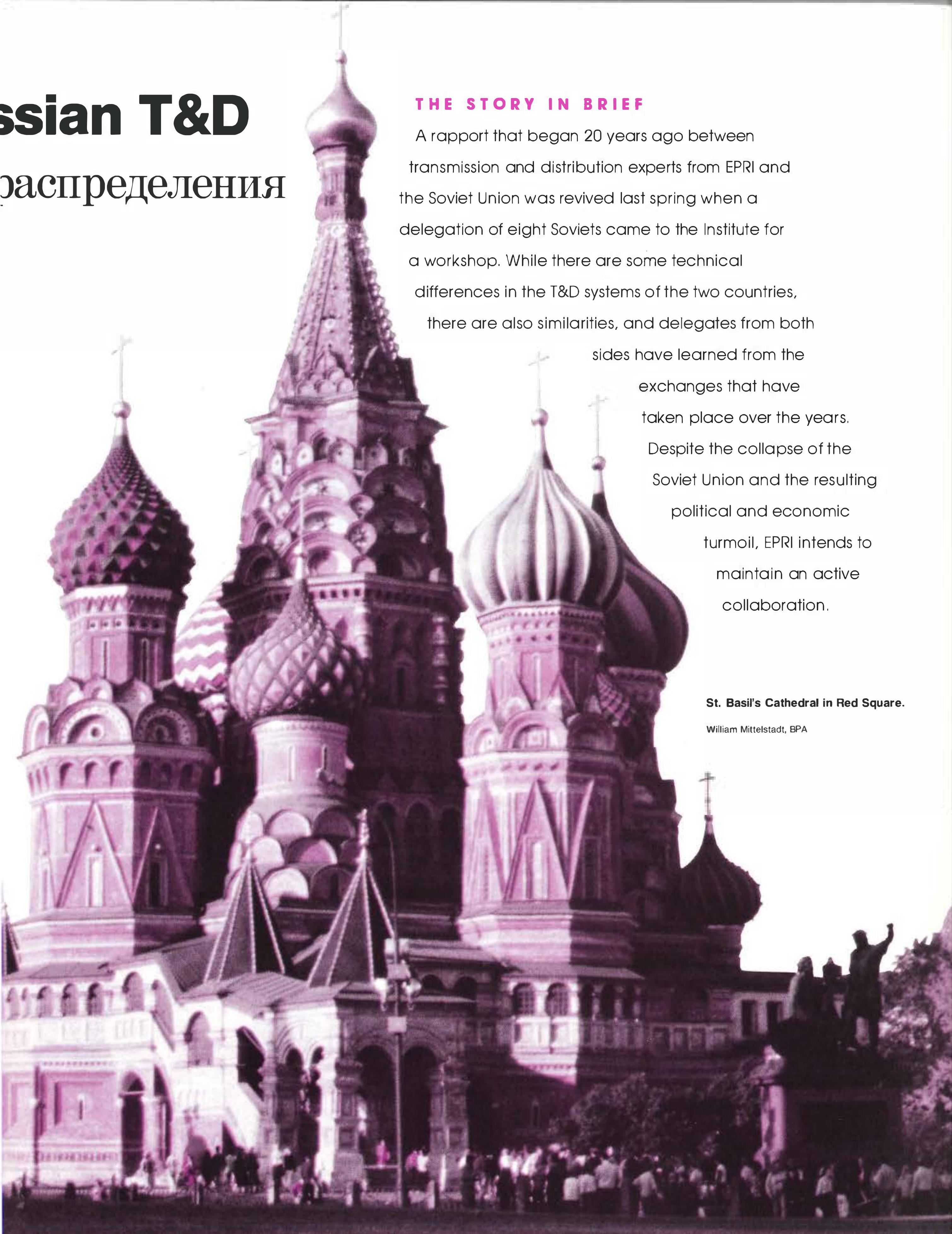
The 1150-kV ac line slices through the barren and windy steppes of Kazakhstan, spans the mile-wide Ob River, and traverses mountainous regions. It was erected to help deliver the fruits of the Soviet Union's power resources, largely concentrated in the east, to the country's population, largely concentrated in the west.

Such severe climatic conditions and inconvenient distribution of resources like coal deposits and hydroelectric sites are not commonly encountered in the United States. Nor is a 1150-kV transmission line likely to be built in this country in the foreseeable future. Nevertheless, through a series of exchanges with Soviet scientists over the years, EPRI's experts have learned that, on a technical level, the electric transmission and distribution systems of the United States and the former Soviet Union—now the Commonwealth of Independent States—have more similarities than differences and that both parties can benefit from sharing information.

The EPRI-Soviet T&D rapport, which began nearly 20 years ago, was revived recently when a delegation of eight Soviet scientists came to the Institute for a workshop on innovations in high-capacity transmission lines. The group included the head of the Soviet Ministry of Power and Electrification, which at the time controlled transmis-

ssian T&D

распределения



THE STORY IN BRIEF

A rapport that began 20 years ago between transmission and distribution experts from EPRI and the Soviet Union was revived last spring when a delegation of eight Soviets came to the Institute for a workshop. While there are some technical differences in the T&D systems of the two countries, there are also similarities, and delegates from both sides have learned from the exchanges that have taken place over the years. Despite the collapse of the Soviet Union and the resulting political and economic turmoil, EPRI intends to maintain an active collaboration.

St. Basil's Cathedral in Red Square.

William Mittelstadt, BPA

sion for the entire country. That man, Anatoly F. Djakov, is now minister of fuels and energy for Russia.

The workshop was held in May of last year, three months before the failed coup that catapulted the Soviet Union into political and economic turmoil. Despite the uncertainty that has come with the collapse of the communist system and the expiration of the Soviet Union, EPRI intends to maintain an active collaboration. EPRI's delegates plan to return to Russia in August of this year, as outlined in a protocol signed at the workshop by representatives from both countries.

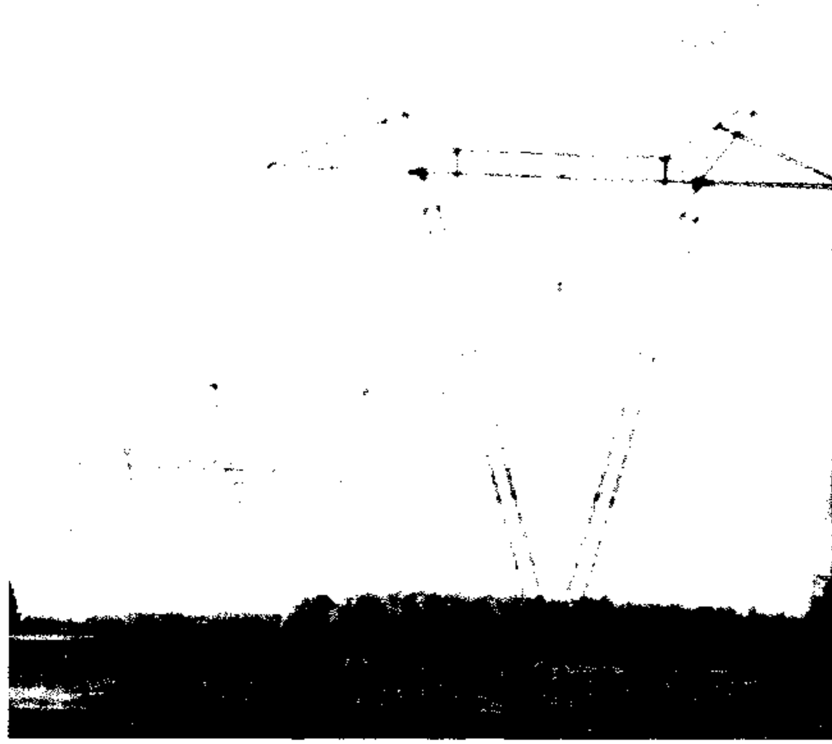
Different but similar

Before it dissolved with the resignation of Mikhail S. Gorbachev last December, the Union of Soviet Socialist Republics was the largest country in the world. Occupying one-sixth the land area of the globe, it was nearly two and a half times the size of the United States. Unlike the electric power system of the United States—which has evolved gradually, shaped by economic consideration for pooling resources among neighboring utilities and regions—that of the Soviet Union was conceptualized from the beginning. The idea of the systematic creation of a national, unified power grid was embodied in Vladimir Ilyich Lenin's famous dictum: "Communism is Soviet government plus the electrification of the whole country."

Today the ex-Soviet electric grid consists of three networks: the "national" integrated power grid, which encompasses about seven time zones and incorporates roughly 85% of the country's generation; the power grid of the Far East; and that of Central Asia. The U.S. grid also consists of three networks: one in the east, one in the west, and one in Texas. But while small power transfers are made between the U.S. networks through dc ties, the Soviet networks are not yet interconnected.

There are a few basic differences in the way power has been delivered in the Soviet Union, aside from the country's use of longer, higher-voltage transmission lines. One

William Mittelstadt, BPA



The former Soviet Union's 1150-kV transmission line, the highest-voltage line in the world, cuts through a field outside Kokchetav.

William Mittelstadt, BPA

Live-line maintenance of the 1150-kV line.

example is that in cities with large apartment complexes, hot water is piped directly from cogeneration plants into homes for bathing, heating, and other everyday uses. Generally though, on a technical level, the T&D system established by the Soviet Union is much the same as that in the United States, says Narain Hingorani, vice president for EPRI's Electrical Systems Division, who has been involved in exchanges with Soviet scientists since the early 1970s.

"There are many similarities between the systems simply because in order to ensure service and minimize the cost of electricity, it is necessary to maximize the use of the generation capacity that you build," says Hingorani, noting that the interconnected systems of both countries were created to accomplish these aims. "The function of transmission is not just to deliver power from one place to another. It is much broader than that: to pool the generation and load centers in a region to maximize the use of available generation and take advantage of diversity in weather, time zones, and fuel."

Differences between the power systems of the United States and the former Soviet Union are more apparent on the economic and administrative levels, a direct reflection of the differences between a decentralized capitalist system and a centralized communist system. One key economic difference is that Soviet electricity rates have been heavily subsidized by the government and have not reflected the actual cost of generation and transmission.

On the administrative level, a central dispatching board in Moscow has controlled the functions of the main integrated power grid. Overseeing the actions of this board was the Ministry of Power and Electrification, one of the former union's most powerful ministries. Aside from controlling more than 90% of the country's installed electric power capacity and output, this body was responsible for transmission nationwide. Also involved in electric power, from a manufacturing standpoint, was the Ministry of Electrotechnical Industry.

With the collapse of the Soviet Union, the Russian government has taken possession of these and most other union ministries. At this time, it is unclear how control of the power system will be maintained in the new Commonwealth of Independent States.

"Right now these ministries are under the Russian Federation, that is for sure," Anatoly Shurygin, first secretary for the Office of Science and Technology at the Russian Federation Embassy in Washington, D.C., said in an interview early in January. "But it is premature to say which will remain and what is going to be their final organization with Russia."

Regardless of what has happened to the ministries, the former republics—including those that do not belong to the new commonwealth—are likely to stay interdependent in terms of power generation and transmission, George M. Sergeyev suspects. Since 1976 Sergeyev has been a foreign relations manager for a transmission research institute within the Soviet Ministry of Power and Electrification. He expects the future electric power relationship among all the republics to be much like that among European countries, which have interconnected grids and regularly transmit power across their borders.

"There may be some impact from the political changes on the power system of the country, but personally, and from what I have heard, I believe the impact will not be very strong," he says. While technically it would be possible for individual republics to gain control of their own power systems, Sergeyev says, it would not be in their interest to do so. "Then they could not rely on getting or exporting extra power from or to the other republics if they needed to," he explains.

The EPRI-Soviet link

The impetus for EPRI's first T&D contact with the Soviet Union came from the White House in the early 1970s, before the Institute was even established. During that time the Nixon administration, in an effort toward detente, initiated a variety of exchange programs with the Soviet Union in such fields as medicine, agriculture, and space. Coincidentally, Richard Balzhiser, now president and CEO of EPRI, was in the White House Office of Science and Technology, serving as assistant director for energy, environment, and natural resources. He headed up the exchange program for energy research and development.

Back then Hingorani worked at the Bonneville Power Administration, and Frank Young, now director of the Electrical Systems Division, worked for Westinghouse. Already recognized as leaders in T&D, the two became members of a transmission committee involved in the energy exchange program. Transmission delegates from both sides began their collaboration by identifying key areas of mutual interest, such as the design of transmission lines to carry voltages greater than 1000 kV, the design of towers to support these lines, line insulation, and reliability. Before long, joint research projects were initiated.

As Young describes it, the work began in small steps. For example, he teamed up with a Soviet researcher to investigate a discrepancy in data from insulator tests. Because the two countries used different testing methods, the data they plotted resulted in curves that did not match. Young and his Soviet counterpart exchanged information and worked in one another's laboratories. In the end, they managed to duplicate each other's testing systems and were able to generate the very data that had previously seemed foreign to them.

"We had to learn how to talk with each other," Young says. "We had to learn what the definitions of terms were and how we interpreted data and what instruments were used. And we accomplished that. We can now talk with each other without that kind of barrier."

The U.S. and Soviet researchers had just attained this level of understanding when the Soviets invaded Afghanistan in 1979. President Jimmy Carter ordered that the exchange programs be terminated immediately, and the EPRI-Soviet collaboration came to an abrupt halt. That was the end of the relationship for several years.

Then in the late 1980s, Young was in

Other EPRI-Russian Connections

EPRI staff members demonstrate a fossil fuel power plant software program for Anatoly F. Djakov, minister of fuels and energy for Russia. Seated, from left to right, are Djakov, John Scheibel, and Walter Piulle; standing are Tony Armor, George Touchton, and Kurt Yeager.

Transmission and distribution is just one area in which EPRI is collaborating with the former Soviet Union. Before the collapse of the union, several divisions within the Institute had individually initiated projects with Soviet scientists. EPRI is now exploring the possibility of broadening such individual collaborations into an Institute-wide technology exchange with the Russian Republic.

Kurt Yeager, EPRI's senior vice president for technical operations, met with Anatoly F. Djakov, minister of fuels and energy for Russia, when Djakov came to the Institute for a T&D workshop last May. The two discussed the possibility of a broader exchange program. Djakov has invited Yeager to come to his country this year to further investigate the idea of such an exchange. Accompanying Yeager will be Tony Armor and Walter Piulle of EPRI's Generation and Storage Division.

Yeager is interested in a "mutual technology exchange of comparable value." The Russian technologies and practices of interest to EPRI include district heating and the combustion of low-quality coals. The Russians are interested in learning more about emissions reduction and the design of power plants for easier operation, among other areas.

In the meantime—like the Electrical Systems Division—the Generation and Storage, Environment, and Nuclear Power divisions have been involved in their own projects with the Soviet Union.

The Generation and Storage Division has been in contact for over two years with Soviet utilities and research organizations that serve them. This relationship began in 1989 when Armor, director of the Fossil Power Plants Department, and a Russian-born contractor visited the Soviet Union as guests of Leningrad's Central Boiler and Turbine Institute. While in the USSR, they toured major fossil fuel power stations, manufacturing facilities, research and development laboratories, and universities. The visit alerted Armor to some potential areas for technical cooperation. About a year ago, Armor sent staff members back to investigate the Soviet practice of adding oxygen to the feedwater of fossil-fired boilers to control corrosion. EPRI is now testing this technology in two U.S. fossil plants.

The Environment Division has a collaborative agreement with the Energy Research Institute of the Academy of Science of the USSR State Council for Science and Technology. The agreement, initiated in June 1990, includes four projects. Two of the projects have already been completed. One involved the use of energy systems models to investigate carbon dioxide trends and mitigation costs for the Soviet Union and Eastern European countries. The other was a workshop on national energy strategies, held at Princeton University last year. The remaining two projects pertain to decision making on energy systems and to the evaluation of computer models of pollutant transport and transformation.

The Nuclear Power Division has been involved with the Soviet Union through a program geared toward understanding the safety aspects of nuclear power plants. EPRI is managing the program, which is called the Advanced Containment Experiments (ACE) and involves 19 countries that rely on nuclear power. Now in its third year, the program was established to explore the physical phenomena involved in severe accidents. The goal is to better understand how the accidents happen, with the ultimate aim of making nuclear plants safer. While work for this program is conducted all over the world, the bulk of it is taking place in the United States. □

charge of a project on the technical limits of transmission system operation. Balzhiser, who was executive vice president at EPRI at the time, was interested in getting an international perspective on the issue, including input from the Soviets. He was also curious about what technical progress that country had made over the past decade.

Young arranged a trip to Moscow and Leningrad through contacts he had made in his previous exchange. When he returned, he saw a country transformed by Gorbachev's program of economic and social reforms. Americans swarmed the hotels of Moscow, hawking everything from Coca-Cola to computers. Young even noticed a change in attitudes.

"Back in the 1970s," he recalls, "the Russians were very somber—very, very somber. They would shake a finger at us and say, 'You Americans laugh and smile too much; you ought to save that for special occasions.'" But upon his return in the late 1980s, Young says, "they were laughing and joking just like we would at home. They seemed much more relaxed."

In the process of gathering information for his project, Young found the Soviets eager to link up with EPRI once again. So when he got back to California, he contacted the U.S. State Department to determine whether the exchange program could be revived. At that time, the cold war was still in progress and the State Department was not eager to initiate such a program.

In the meantime, though, Hingorani had been in contact with the Bonneville Power Administration on the same issue. And with support from Chuck Clark, chief engineer for BPA, and Ralph Gens, former chief engineer for BPA, Hingorani took the project into his own hands. "We recognized that there were quite a few areas that were of mutual interest and a lot of give-and-take possibilities," Hingorani explains. "There was definitely a need for a renewed relationship."

As Clark puts it, "The time appeared ripe again. There were some areas in which the Soviets had done some good work, and it was clear that we could benefit by listening to what they'd been up to. This kind of information had not been exchanged as widely in professional and technical societies as it had been with other countries."

The May 1991 workshop, held at EPRI's headquarters in Palo Alto, California, was the first official exchange to result from Hingorani's initiative. With the exception of one delegate, the eight visitors represented an entirely new set of contacts, since many of the experts from the earlier exchanges had retired from their positions. Aside from Minister Djakov, the delegates included the director of the All-Union Electric Power Research Institute (VNIIE), one of a number of research organizations directed by the Ministry of Power and Electrification; four other experts from VNIIE; and two officials in long-distance power transmission, also under the same ministry.

"It was a fishing expedition on both sides," says Young. Papers were presented on transmission tower testing techniques, compact transmission technology, equipment wear and damage, and experience with transmission lines over 1000 kV. Leaders in T&D, both from within EPRI and from utilities across the United States, participated in the workshop. Among the 12 U.S. experts from outside the Institute was Gens, who led the U.S. delegation on transmission issues during the 1970s exchanges.

The two-day workshop was just one segment of an eight-day trip for the Soviets that included a visit to the U.S. capital, a tour of EPRI's Transmission Line Mechanical Research Center in Haslet, Texas, and a conference at BPA, at which the Soviet delegates presented papers to BPA's technical engineering staff. Before leaving EPRI, leaders of the Soviet and EPRI delegations signed a protocol that calls for a second workshop in the USSR in August of this year and outlines a plan for further cooperation in innovations with transmission lines of 345–750 kV and of 1000 kV and above. Specifically, the two sides have pinpointed overhead transmission, transmission substations, control and protection, power system planning and operation, and environmental engineering as areas for collaboration.

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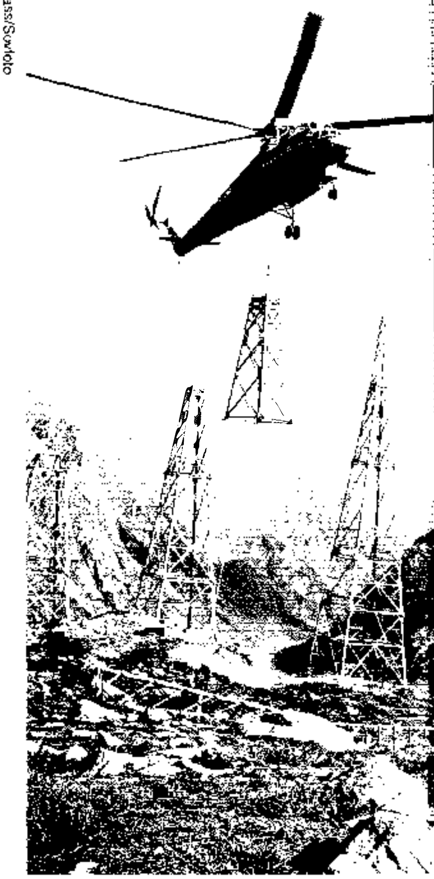
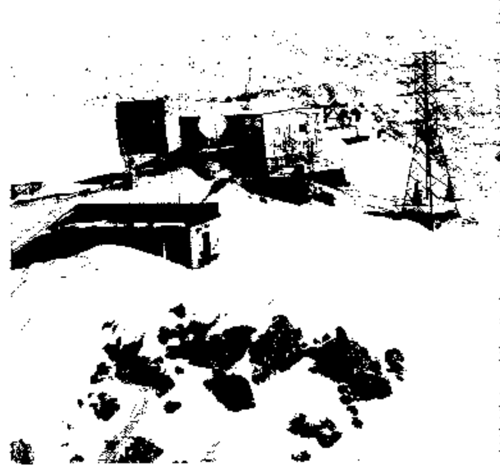


A helicopter helps erect transmission towers in the Caucasus Mountains.

Transmission lines near a repeater station in the snowy Gissar Range, nearly 10,000 feet above sea level in the Central Asian region of the former Soviet Union.



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A MEETING OF THE MINDS: THEN AND NOW

Narain Hingorani (standing) at an exchange meeting in the USSR in 1971. Seated to the left of him is Ralph Gens, former chief engineer for BPA.

T&D delegates from the United States and the Soviet Union gathered in BPA's lobby last May. Pictured in the front row, from left to right, are Victor S. Rashkes, Larisa V. Timashova, Sergey V. Krylov, Narain Hingorani, Donald T. McGillis, and Vladimir A. Shkaptsov. In the back row are Ralph Gens, Vladimir V. Iljinichnin, Dmitry S. Savvaitov, William Mittelstadt, Chuck Clark, Minister Anatoly F. Djakov, Oleg A. Nikitin, and Debra Coleman.

Sherry Lind, BPA

Give and take

The official purpose of last May's workshop was the exchange of technical information between U.S. and Soviet delegates. But soon after members of the foreign delegation arrived, it became clear that they were interested in other matters as well.

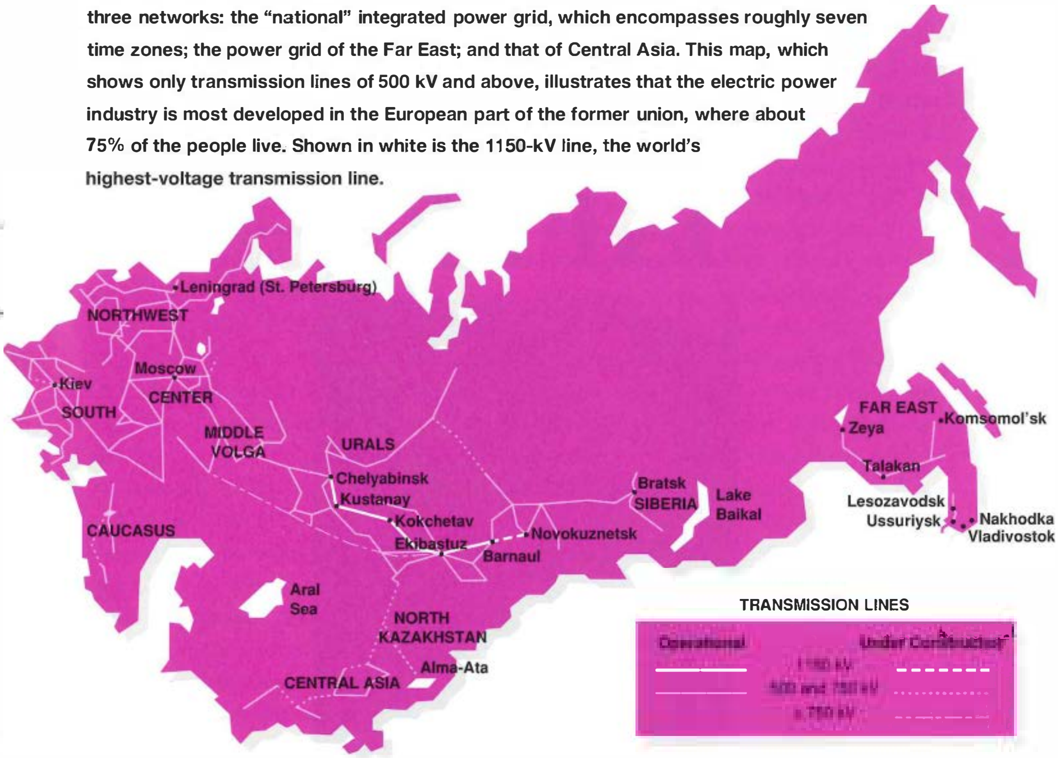
"One of the main reasons they were here was to see how we operated organizationally—to see how we motivated people," says Balzhiser, who participated in giving the visitors a tour of EPRI's headquarters. "One of the things they picked up on was that we have coffee stations. They asked whether the refreshments were available for everybody and whether we gave them away free."

The Soviets also were very interested in finding out how the U.S. electric power system works. Their questions included, How is EPRI organized? How is a utility like BPA organized? Where do these entities get their money? How are large projects managed? How does the industry charge for electricity?

"There was a great deal of curiosity from them about BPA," Hingorani says. "They wanted to know how a government-owned agency is able to be so successful and loved, so to speak. They wanted to know what we in the United States were doing that was different, and how they might be able to duplicate that." Indeed, the visitors arrived during a period of major transition in the Soviet Union, and the concerns of many involved in the country's power system appeared to be focused more on administrative than on technical issues.

Some observers believe the EPRI-Soviet link has been something of a one-way exchange, with EPRI providing the bulk of the goods for Soviet benefit. But there are a number of areas in which the Soviets have excelled, and EPRI is learning from them also. "It's not always easy to say that somebody knows more than we do," says Hingorani. "But I would say that they have done an awful lot of work that we could learn from in the areas of transmission lines over 1000 kV and compact transmission."

THE SOVIET TRANSMISSION GRID The electric grid established by the Soviet Union consists of three networks: the "national" integrated power grid, which encompasses roughly seven time zones; the power grid of the Far East; and that of Central Asia. This map, which shows only transmission lines of 500 kV and above, illustrates that the electric power industry is most developed in the European part of the former union, where about 75% of the people live. Shown in white is the 1150-kV line, the world's highest-voltage transmission line.



Compact transmission technology, applicable at all voltage levels, involves bringing conductors closer together to increase the transmission capacity of available corridors without increasing magnetic fields. According to Hingorani, Soviet scientists have investigated new geometries for subconductors that successfully accomplish this objective. EPRI can benefit directly from this work.

In the area of higher-voltage transmission, the Soviets, who were the first in the world to erect a transmission line over 1000 kV, have clearly been leaders. The Soviet Union's 1150-kV line, commissioned in 1985, today stretches 1240 miles from Barnaul in West Siberia to Chelyabinsk at the southern edge of the Ural Mountains, which divide the European section of the former union from Siberia.

The line is one small component of a much larger ring of 1150-kV transmission that the Soviet Union intended to install over the next two decades. While the 1240-mile stretch has been constructed to accommodate 1150 kV, only two sections of it are operating at that voltage. The remainder is being operated at 500 kV, pending the construction of transformers and other related equipment necessitated by the higher voltage. It is not known whether the new commonwealth will follow through with the planned expansion of the 1150-kV system.

Because of public concern about electric and magnetic fields, U.S. utilities have no current plans to implement such technology. Nevertheless, communication with Russian T&D experts is keeping EPRI informed about progress and experience in this area. According to Hingorani, much of the work on these lines is applicable to lines of lower voltage. And, he says, it is conceivable that at some point in the future this country could construct such lines.

There are other ways in which EPRI can benefit from an ongoing relationship with scientists in the new Commonwealth of Independent States. For instance, EPRI stands to benefit from business opportunities if organizations in the commonwealth become licensees of such EPRI-developed technologies as FACTS (Flexible AC Transmission Systems). The brainchild of Hingorani, FACTS technology is currently under development at EPRI and has drawn the attention of T&D leaders worldwide. It involves the use of high-speed electronic controls to increase significantly the usable capacity of transmission lines.

Already scientists from Russia and other former Soviet republics have expressed great interest in FACTS technology. Three representatives from the All-Union Electrotechnical Institute (VEI), including the director of the organization, are scheduled to come to EPRI early this February specifically to learn about FACTS. (VEI was part of the Electrical Equipment Ministry.) That visit, which is unrelated to the May workshop, was arranged after the deputy director of VEI approached Hingorani with the idea during a meeting of an international professional organization in Delhi, India. Hingorani was happy to receive his Soviet colleagues.

"We have something to give to them, and we also have something to gain from them," he says. "That is the basis on which we want to enhance our relationship." Hingorani does not expect the current turmoil in the now-defunct Soviet Union to deter EPRI's efforts to collaborate on T&D. In fact, he says, the changes call for a greater effort on EPRI's part. "It's easy to say, 'Let them worry about their own problems. Let them sort things out for themselves,'" Hingorani notes. "But I think it's natural that if the USSR accepts democracy as the basis for its society, then we should make a little extra effort to reach out and say, 'We'll work with you.'" ■

This article was written by Leslie Lamarre. Background information was provided by Narain Hingorani, Frank Young, and Richard Kennon, Electrical Systems Division.

ROBERT JAFFEE

A Scientist for All Seasons

Championing the use of titanium and high-purity steels for utility applications, Jaffee made important contributions to safer, more durable generating equipment.

WHEN ROBERT JAFFEE BECAME HEAD OF EPRI'S MATERIALS SUPPORT GROUP, in 1975, he was already a world-renowned metallurgist, but his new boss—now EPRI president—Richard Balzhiser refused to give him a budget. "I remember Bob arguing and arguing against my position," Balzhiser recalls, "but I told him that I didn't want materials research to become an end in itself. I wanted him to convince other EPRI program managers to invest in his work."

By the time Jaffee died, last November, his entrepreneurial spirit not only had gained him moral and financial support from EPRI colleagues but also had created some revolutionary changes in the way critical materials are produced and used in electric generating equipment. "He not only produced good science but had the follow-through capability to make sure a product got built and got put to use," Balzhiser says. "He really was a scientist for all seasons."

A passion for titanium

For the electric power industry, with its huge, complex equipment that often operates under extreme conditions, the development of exceptional materials can literally be a matter of life and death. Steam turbine blades weakened by a combination of mechanical stress and corrosion, for example, may break off at high speed, penetrate the surrounding metal casing, and cause damage and injury in a generator building. Catastrophic failure of a turbine rotor can release enough energy to destroy the whole building.

Such failures are, fortunately, extremely rare, but just the possibility that they could occur means that utilities must take a cautious attitude toward inspecting and replacing critical turbine elements. Both the equipment failures and the precautions taken to avoid them are costly, so the utility industry has long sponsored a major materials research program aimed at increasing the safety and expected lifetime of turbines. Robert Jaffee spearheaded this effort at EPRI.

Jaffee's special field of expertise—his professional passion, as friends have described it—was titanium, a lightweight metal that is particularly resistant to corrosion. It has traditionally played a major role in alloys for aircraft bodies and jet engines, and Jaffee became a leading expert in its metallurgy during his 32 years with the Columbus Laboratories of Battelle Memorial Institute. Before he could exercise the full value of this special expertise at EPRI, however, Jaffee had to master what was for him the relatively unfamiliar territory of ferrous metallurgy, which is so important for utility-scale turbines.

Eventually he discovered an important connection: the substitution of a high-strength titanium alloy for the steel alloys normally used in steam turbine rotor blades could significantly retard their corrosion. Particularly susceptible were the blades in the next-to-last (L–1) row of a turbine, where acid salts deposited by droplets of condensing steam can induce pitting corrosion. Fatigue failure caused by such corrosion is the primary cause of forced outages in fossil-fired low-pressure turbines.

"Making a complex new alloy like this isn't easy," says John Stringer, who directs the applied research portion of EPRI's Office of Exploratory and Applied Research. "Titanium alloys are intrinsically more corrosion-resistant than steel, but they are not very good at damping vibrations. To get the right physical properties, you have to develop a particular microstructure by means of special thermal-mechanical treatment—'heat it and beat it,' as we say. Bob worked with Gerd Luetjering of Germany to produce an ultrafine-grained structure that had the desired properties for turbine blades. He was a bulldog that way: he would identify a problem, then a solution, then the problems with the solution, and finally a way to solve those problems."

Superclean steel

This dogged determination really paid off when Jaffee tackled the problem of reducing turbine rotor failures. Here the challenge was not so much developing a new alloy as fundamentally changing the way rotor steel is refined and forged.

The failure process generally begins with the appearance, at high temperature, of cracks associated with small particles of impurities in the metal. Sulfur is commonly introduced during steelmaking and has a deleterious effect on steel properties. Traditional practice has been to remove it by adding manganese, which reacts chemically with the sulfur. After this step, however, some particles of manganese sulfide remain, and Jaffee set out to find a way of producing "superclean" steels that are virtually free of sulfur, manganese, and other troublesome impurities, such as silicon.

The approach he championed through nearly a decade of EPRI-sponsored laboratory work was to use secondary refining techniques, such as vacuum degassing and deoxidation, to achieve new levels of purity. This work eventually led to turbine rotors made from superclean steels that have significantly improved fracture toughness. The research also revealed that the superclean techniques can improve the performance of steel alloys at low temperatures, enabling foundries to produce rotors that do not have to be prewarmed before startup.

"Bob pushed this idea from its start in low-budget university research right through to its application in rotors installed on utility equipment," says Stringer. "His vigor and reputation helped ensure that the right people from different industries got involved. As a result, there has been a worldwide change in the way rotors are made. Unfortunately, this advance has been applied most vigorously abroad, and U.S. turbine manufacturers are having to buy their rotors from offshore sources. That was a big disappointment for Bob. He had always hoped that a resurgence in making this kind of specialty steel would help revitalize the American steel industry."

New frontiers

In addition to his research work, Jaffee was widely recognized for organizing a series of international colloquia focused on particular problems in metallurgy. Each of these conferences resulted in proceedings that are still considered important reference sources. His 23 books and 45 U.S. patents also attest to Jaffee's stature and productivity. Among many professional activities, he served as president of the Metallurgical Society and as chairman of the board of governors of Acta Metallurgica. He was also a member of the National Academy of Engineering and a fellow of the American Society of Metals.

Although Jaffee had officially retired from EPRI, he continued to explore new frontiers in materials research as an EPRI consultant and as a consulting professor at Stanford University. During this period, he concentrated largely on developing a kind of steel that could be used to make rotors for both steam and gas turbines. Such a development would make it possible to integrate these turbines more closely in a combined-cycle plant, perhaps even to combine the two on a single shaft. Typically, he also continued to probe entirely new fields of endeavor, developing a novel method for producing large single-crystal silicon ingots for power electronics applications.

"Over the years, EPRI's greatest key to success has been to pick the right people to begin with and then expect them to attract other good people," concludes Balzhiser. "That certainly held true for Bob. He was already an acknowledged authority when he came here; then he brought in people like John Stringer to build a world-class group of materials scientists. I did, by the way, eventually give Bob a small discretionary budget of his own. One of the first things he did with it was to sponsor some research at Berkeley that led to a new steel for generator retaining rings. He had a real gift for leveraging his own remarkable scientific talents." ■

This article was written by John Douglas, science writer, from interviews with EPRI president Richard E. Balzhiser and John Stringer, Office of Exploratory and Applied Research.

TECH TRANSFER NEWS

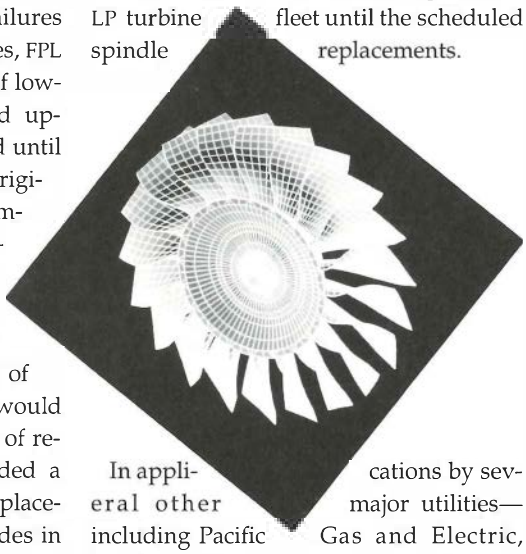
FPL Uses BLADE Code to Analyze Failures

EPRI's finite-element computer code BLADE played an important role in decisions at Florida Power & Light regarding repair and replacement of low-pressure steam turbine rotor blades—decisions that saved the utility an estimated $3 million or more in costs while keeping the units operating reliably.

In response to frequent blade failures that were causing significant outages, FPL decided in 1989 to replace its fleet of low-pressure (LP) rotors, but new and upgraded rotors could not be installed until 1991 or 1992. In the meantime, the original equipment manufacturer recommended placing all six affected generating units on cold standby because of cracked L–1 stage blades. The unavailability of the units, which represent nearly half of FPL's fossil generating capacity, would have required enormous purchases of replacement power. The utility needed a middle course between costly replacement of all the LP turbine rotor blades in order to keep the units operating, on the one hand, and simply taking them out of service until 1992 and buying replacement power, on the other.

FPL chose to develop and pursue a process to identify potential blade failures and prevent recurring problems. A major element in the process was EPRI's BLADE (Blade Life Algorithm for Dynamic Evaluation) code, an interactive computer software package for evaluating blade designs and analyzing vibration fatigue. The code was used to perform dynamic analyses of each stage of the low-pressure units that had experienced blade failures. A metallurgical assessment of cracked L–1 stage blades, in conjunction with a BLADE evaluation, helped the utility determine that crack initiation and growth was caused by low-cycle fatigue.

Thanks to the focusing of corrective attention that resulted from the systematic evaluation process, interim countermeasures (including blade root machining to remove small cracks) made blade replacement unnecessary and averted an eight-week forced outage at one FPL generating unit. At two other stations, the utility was able to defer blade replacement and machining to off-peak periods for additional savings in outage costs. FPL is confident that it can reliably operate its LP turbine fleet until the scheduled spindle replacements.



In applications by several other major utilities—including Pacific Gas and Electric, Southern California Edison, and the Tennessee Valley Authority—BLADE has produced substantial documented benefits. The code was developed for EPRI by, and is commercially available from, Stress Technology, Inc., of Rochester, New York. A new, enhanced version for the IBM PC can help utilities analyze and troubleshoot high-temperature blades and address creep fatigue and hot corrosion in blades for both steam turbines and combustion turbines. To complement BLADE, EPRI has developed a system called STEM for the on-line measurement of dynamic blade stresses. BLADE is part of a family of EPRI software tools that can help utilities improve the efficiency, reliability, and operating life of rotating machines. ■ *EPRI Contact: Thomas McCloskey, (415) 855-2655*

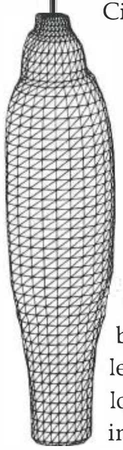
Ultrasonic Survey Cuts Cost of Cavern Maintenance

An ultrasonic surveying tool introduced in the United States by EPRI during the underground solution-mining of an Alabama salt dome for the country's first compressed-air energy storage (CAES) plant has also been successfully used to determine the volume and shape of a pressurized natural gas storage cavern. This application represents another first for the technology in this nation.

Given the success of this effort, a subsidiary of Texas Utilities Company expects to save more than $5 million over the next five years by using the echo-logging method for regular surveys of its three natural gas storage caverns. Meanwhile, the U.S. government is planning to use the method to monitor its strategic petroleum reserve, which is stored in salt caverns along the Gulf Coast.

Texas Utilities Company is currently the only U.S. electric utility that uses salt caverns to store gas for its power plants, but other utilities are considering the approach in order to reduce fuel costs and ensure gas availability. Every five years, as part of regular cavern maintenance, Texas Utilities has had to remove all gas from each of the caverns, which are more than 4000 feet below the surface, and fill each with water before lowering a sonar surveying tool to check for cavern shrinkage or closure. The brine is then pumped out for disposal as the cavern is repressurized with gas. The costly process can take as long as a year, during which time a third or more of the utility's 13 billion cubic feet of cavern storage capacity and gas supply is unavailable.

Much less expensive than sonar-based survey methods, the echo-logging transmitter-receiver was developed for use at the world's first CAES site in Huntorf, Germany. Working closely with Alabama Electric Cooperative, EPRI arranged for the system's use in monitoring dimensions during the solution-mining of a 19-million-cubic-foot cavern in an underground salt dome at McIntosh, Alabama, where AEC's CAES plant began operation last year. The system was used to survey the McIntosh cavern three times during the 22-month mining process.



Citing the echo-logging method's successful demonstration in two applications of growing interest to electric utilities, EPRI project manager Ben Mehta says that "utilities can use the technology to monitor the shape and size of caverns quickly and economically during the solution-mining process. In addition to its expected use by utilities and by the government for the petroleum reserve storage caverns, echo logging is likely to be used at many industrial installations where liquid hydrocarbons are stored in salt caverns." ■ *EPRI Contact: Ben Mehta, (415) 855-2546*

Taipower Benefits From NDE Training for IGSCC

Taiwan Power Company is the latest (and perhaps the most distantly based) utility taking advantage of the unique training programs developed at EPRI's Nondestructive Evaluation (NDE) Center for containing intergranular stress corrosion cracking (IGSCC) in the recirculation piping of boiling water reactors. The programs have been extensively used by U.S. utilities that operate BWRs.

Separate training programs covering IGSCC detection, sizing, and weld overlay repair examination were developed by EPRI with funding from the BWR Owners Group in response to Nuclear Regulatory Commission directives to utilities in the early 1980s to demonstrate that their ultrasonic examination personnel, equipment, and procedures were effective in addressing IGSCC. It is difficult to detect and size such cracks with ultrasonic technology, but the technique can be effective. Continuing in-service inspections are required. Supported by a large inventory of equipment, calibration blocks, and laboratory and field samples, the inspection training programs are conducted at the EPRI NDE Center in Charlotte, North Carolina.

Taipower operates six nuclear generating units on Taiwan, including four BWRs that have large-diameter recirculation piping susceptible to IGSCC. Periodic training of personnel is required to maintain proficiency in the use of ultrasonic inspection technology, but it would have been prohibitively expensive for Taipower to develop its own formal training program.

As a member of the BWR Owners Group, the Taiwan utility has sent more than two dozen utility personnel over the last decade to attend the NDE Center's IGSCC training programs, thereby realizing estimated cost savings of over $2 million. The success rate of Taipower personnel in operator performance examinations and qualification has been significantly higher than the overall trainee average. "The training programs at the EPRI NDE Center have been very effective and beneficial," says Taipower's Kai-Seng Wong.

Adds Soung-Nan Liu, an EPRI program manager in the Nuclear Power Division's Component Reliability Program, "By applying techniques learned during the NDE Center's courses, Taipower personnel are better equipped to perform IGSCC inspections while piping remains in service, thereby helping the utility avoid unnecessary pipe replacement and the associated power replacement costs." ■ *EPRI Contact: Soung-Nan Liu, (415) 855-2480*

EPRI a Major Presence at IEEE T&D Show

Six new TLWorkstation™ software modules were among the highlights of the latest EPRI products and research results introduced at the IEEE Power Engineering Society Transmission and Distribution Exposition—the electric power industry's largest commercial and technical event—in Dallas, Texas, last September. Over 14,000 people attended the five-day gathering, which is held every two and a half years. EPRI's large exhibit area included representatives of a number of companies that are commercializing EPRI products. Utility engineers were able to see many of the hardware and software products of EPRI's Electrical Systems Division demonstrated for the first time.

New software modules incorporating quicker approaches to calculating right-of-way sizing, power transfer limits, structural loads, and other parameters of transmission line design add to the growing family of engineering analysis software available from EPRI in the TLWorkstation package. Other displays at the

IEEE show featured EPRI's real-time National Lightning Detection Network, the PCB Spill Monitoring System, the TOMCAT remote manipulator, and the Multiwave™ and Field Star 1000™ magnetic field measurement systems. ■ *EPRI Contact: Rick Shumard, (415) 855-2978*

Ecological Studies

Forest Response to Carbon Dioxide

by Louis Pitelka, Environment Division

Given concern over the possibility of global warming due to increased concentrations of carbon dioxide (CO_2) in the atmosphere, investigators are looking at the role that terrestrial ecosystems—particularly forests in the Northern Hemisphere—may play in moderating any predicted climate change. All green plants remove CO_2 from the atmosphere through photosynthesis, and rising concentrations of CO_2 can increase growth rates in some species. Thus, some scientists have suggested that planting trees might be an effective way to slow the buildup of atmospheric CO_2.

It remains unclear, however, how forests as a whole respond to changes in atmospheric CO_2, particularly over long periods of time. A variety of factors—such as the availability of water and mineral nutrients—can affect the ability of individual plants to absorb CO_2. In addition, long-term exposure to higher levels of CO_2 may create changes in ecosystem composition and function that affect overall CO_2 absorption.

ABSTRACT *It has been suggested that planting trees could help slow the buildup of carbon dioxide in the atmosphere. Since elevated levels of CO_2 are known to enhance photosynthesis and growth in many plants, it is possible that trees could become progressively more effective in storing carbon as atmospheric CO_2 increases. However, early results from experiments with ponderosa and loblolly pines indicate that the relationship between tree growth and rising CO_2 concentrations may be more complex than scientists once thought. In these experiments, the response to elevated CO_2 has been highly dependent both on species and on mineral nutrient levels in the soil. Further work is necessary to clarify the mechanisms involved. This research will ultimately contribute to an integrated model for predicting forest ecosystem response to elevated CO_2.*

Since the beginning of the Industrial Revolution, atmospheric levels of CO_2 have increased more than 25%, and a doubling of CO_2 by the mid to late twenty-first century has been widely predicted. As a major user of fossil fuels that produce CO_2 when burned, the electric power industry has taken an important role in research on the so-called greenhouse effect, by which CO_2 and other gases are thought to increase average atmospheric temperatures and to change climate. As part of this ongoing effort, EPRI and Southern California Edison are cosponsoring a five-year research project to study the response of forests to rising CO_2 levels and to determine some of the key environmental factors that influence this response.

Earlier work

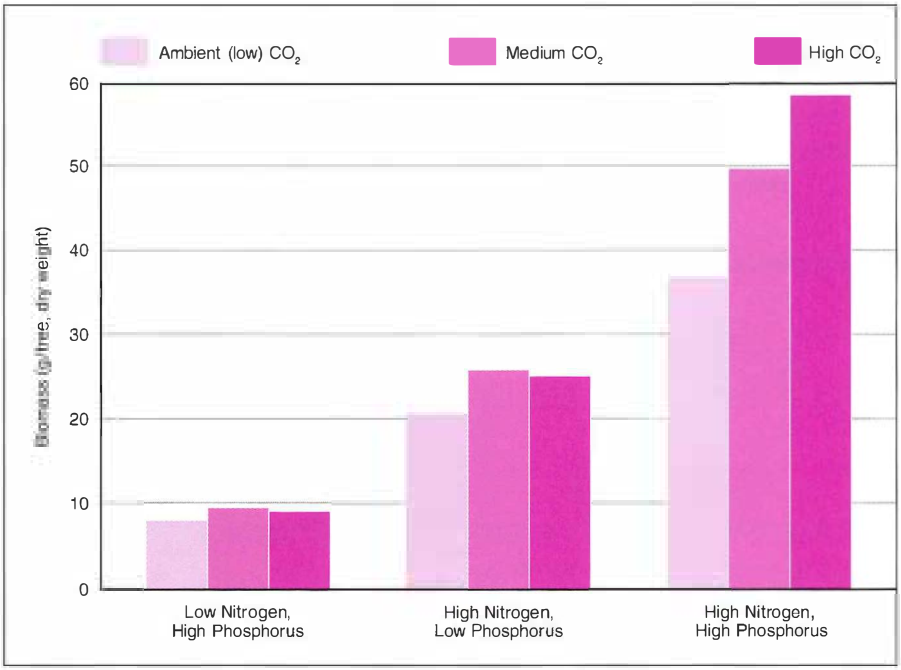
The amount of carbon exchanged annually between the atmosphere and terrestrial ecosystems is about 20 times greater than that produced by the combustion of fossil fuels. Thus, even a small deviation in this amount could have a major effect on atmospheric CO_2 concentrations. Mature forests release CO_2 through the respiration of plants and soil organisms at about the same rate, on an annual basis, that they absorb it through photosynthesis. Young forests tend to absorb more CO_2 than they release, and higher levels of CO_2 may stimulate an increase in the absorption rate of even mature forests. Previous research has indicated, however, that such increases in absorption may be limited by complex, little-understood feedback mechanisms. It is difficult to extrapolate from earlier studies because most were short-term experiments with potted plants in greenhouses. To expand knowledge in this area, EPRI is conducting long-term studies in the field.

In general, the nitrogen content of a plant's leaves limits its maximum potential rate of photosynthesis—and thus CO_2 uptake. A question therefore arises about whether a plant exposed to higher levels of CO_2 would be able to obtain enough nutrition from nitrogen-deficient soils to sustain more rapid rates of photosynthesis and growth. On the one hand, there is some evidence that plants receiving increased CO_2 tend to make more efficient use of the nitrogen available and grow leaves that have a higher carbon-to-nitrogen ratio. On the other hand, some data indicate that this response cannot be maintained indefinitely: as leaves with reduced nitrogen content fall to the ground and decompose, the nutritional quality of the soil slowly deteriorates, exacerbating the nitrogen deficiency.

Also, some plants seem to use water more efficiently as CO_2 levels rise. The mechanism underlying this effect relates to the opening and closing of leaf stomata—the tiny pores through which oxygen, CO_2, and water vapor diffuse into and out of a leaf. With more CO_2 available for photosynthesis, the stomata do not have to open as wide or as often, and less water transpires out of the plant. This effect could be particularly important in determining the response of forests in dry regions, where greater water-use efficiency might enable trees to absorb more CO_2 with no increase in water uptake. However, not enough information is currently available to predict the extent of this response.

In contrast to the efficiency of nitrogen and water use, the efficiency of plant phosphorus use is not expected to increase in response to elevated CO_2. Phosphorus is a key element in the molecules that transfer energy during photosynthesis, so the amount of phosphorus that plants require rises in direct proportion to the reaction rate and CO_2 uptake. Phosphorus also helps regulate the reactions that control carbon storage in a plant. A major result of phosphorus deficiency is a buildup of starch in chloroplasts, which further inhibits photosynthesis. Therefore, plants in phosphate-deficient soils are not expected to show the same growth response to rising CO_2 levels as plants with adequate phosphorus. The severity of this inhibition, however, remains unknown.

Figure 1 Growth response of loblolly pines to various CO_2 and nutrient treatments after about five months. Only the seedlings that had received high levels of nitrogen and phosphorus showed enhanced growth at elevated CO_2.



Previous studies have also hinted at the existence of even more complex feedback processes at the ecosystem level. Increasing atmospheric CO_2 might well alter competition among plant species for dominance of an ecosystem: some species may grow more rapidly while others succumb to declining resource availability. Changes in the availability of soil nutrients, in particular, could favor certain plant types over others and alter the growth of soil microorganisms. How such ecosystem disruptions might affect the overall balance between CO_2 uptake and release is even less understood than the response of individual plants. Future research is necessary to evaluate this issue.

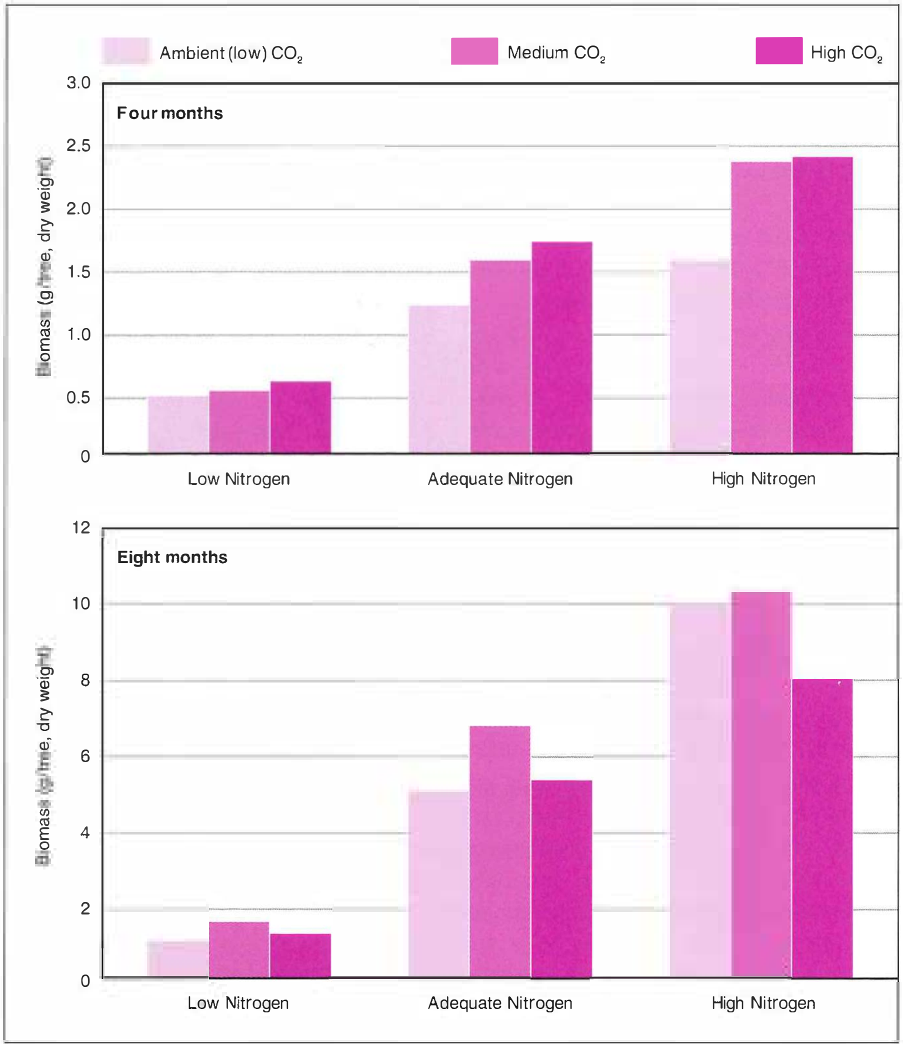
Current experiments

EPRI's research on forest response to CO_2, which began in 1990, aims to fill some of these gaps in knowledge. Two organizations are currently conducting experiments under EPRI and Southern California Edison sponsorship: the Desert Research Institute in Nevada is concentrating on ponderosa pine, and Duke University in North Carolina is focusing on loblolly pine. These pine species, which are among the United States' most important commercial trees, occupy very different habitats. Loblolly forests of the Southeast are relatively moist; their soils are often nitrogen-deficient and, along the coastal plain, may also have phosphorus limitations. Ponderosa forests of the West are much drier, and their growth rates are often limited by soil nitrogen deficiencies.

Project teams are performing experiments both in controlled environments (i.e., greenhouses) and at representative field sites. The controlled-environment studies are providing the majority of information about trees' metabolic adjustments to elevated levels of CO_2 and are laying the groundwork for field studies. In particular, the greenhouse data help determine the levels of nitrogen, phosphorus, and water to be used in field experiments.

The western field site is located at the Institute of Forest Genetics of the U.S. Forest Service's Pacific Southwest Experiment Station in Camino, California, just east of Placerville in the Sierra Nevada. The eastern field study is

Figure 2 Ponderosa pine growth response. After four months (top), the seedlings appeared to be responding as expected to elevated CO_2 at all nitrogen levels. But after eight months (bottom), they showed decreased growth rates at elevated CO_2 levels, even when supplied with large amounts of nitrogen. This unexpected result suggests that increased nutrient-use efficiency in response to rising atmospheric CO_2 is, at best, a short-lived phenomenon. (Note the difference in scale between the two graphs.)



using facilities at a Southern Commercial Forest Research Cooperative site in Duke Forest in North Carolina. At both sites, trees are being grown in open-top chambers in which the level of CO_2 can be controlled but which otherwise provide natural growing conditions. Since the loblolly pines will grow out of the 2.5-meter-tall chambers in two years, they will be completely harvested at that time and the experiments will be repeated. Ponderosa pines are not expected to reach the top of the chambers during the five-year study.

The experiments are testing this general hypothesis: as atmospheric levels of CO_2 rise, tree growth will accelerate; trees with limited water and nitrogen will be able to sustain this increased growth rate (because of more-efficient water and nitrogen use), but trees limited by phosphorus supply will not. To understand the mechanisms underlying the responses, researchers will pay particular attention to how carbon, nitrogen, and phosphorus are partitioned among leaves and other parts of the trees under different conditions, and how stoma function changes. They will also investigate the condition of litter under the trees and the development of mycorrhizae around the roots. (Mycorrhizae are beneficial associations of fungi with roots, associations that help plants absorb nutrients more efficiently.)

Ultimately, this research will contribute to an integrated model for predicting forest responses to rising atmospheric CO_2, including the resulting sensitivity of forest ecosystems to such environmental stresses as limited availability of water and key nutrients.

Results to date

Both the controlled-environment and field site studies are growing groups of trees in three concentrations of atmospheric CO_2: 350 ppm (the present ambient level in the atmosphere), 500 ppm, and 650–680 ppm (the approximate level predicted for the end of the next century if the present rate of buildup continues). Low, adequate, and high levels of nitrogen and phosphorus are supplied to trees in the West; low and high levels, to trees in the East. Groups of greenhouse trees receive different amounts of water. Trees at the field sites receive supplemental water except during short-term water-stress treatments. At specified time intervals, a certain number of trees are harvested and weighed to determine biomass production under the different conditions.

Early results from these experiments indicate that plant response to CO_2 may be even more complex, and even more dependent on soil nutrients, than initially hypothesized. Although the concentration of nitrogen in needles decreased with increasing CO_2 levels (as expected), the hypothesized rise in nitrogen-use efficiency did not necessarily enable plants to respond positively to elevated CO_2. After five months (Figure 1), loblolly pines showed little or no response to enhanced CO_2 when either nitrogen or phosphorus was low. Only when the seedlings were supplied with high levels of nitrogen and phosphorus did they respond positively—as expected—to CO_2.

In ponderosa pines, which grow more slowly than loblolly pines, the results were even more surprising. After four months (Figure 2, top), it appeared that elevated CO_2 might be enhancing growth at all nitrogen levels. (Because of adequate natural soil phosphate, the variations in phosphorus treatment did not have any effect.) However, after eight months (Figure 2, bottom), the patterns had partially reversed. Even with a high level of nitrogen available, ponderosa pines showed a decrease in growth rate at the highest CO_2 concentration. An initial interpretation of this finding is that increased nitrogen-use efficiency may, at best, be a short-lived phenomenon, and that individual trees may not sustain higher growth rates for long periods when exposed to the levels of CO_2 predicted for the next century.

At the very least, the relationship between plant growth and rising concentrations of atmospheric CO_2 appears to be more complicated than scientists initially thought. In particular, high CO_2 levels may inhibit trees' nitrogen uptake for reasons that are not clear. As a result of the experimental findings so far, the researchers are formulating new hypotheses for testing in the later stages of the project. The resolution of uncertainties is likely to require several more years of work.

Instrumentation and Control

Advanced Control System for B&W PWRs

by Siddharth Bhatt and Bill Sun, Nuclear Power Division

ABSTRACT *As digital control systems have become increasingly attractive, and replacement parts for existing analog systems more difficult to find, EPRI has been pursuing a long-term program to help utilities upgrade control technology in nuclear power plants. The latest step in this effort is the development of an advanced control system for Babcock & Wilcox (B&W) pressurized water reactors. Working with the B&W Owners Group, EPRI is developing a highly reliable, flexible digital control system that uses feedback and feedforward logic to tightly coordinate control of major plant systems and subsystems. The fault-tolerant design promises to improve trip avoidance and increase operational flexibility.*

In the early 1980s, EPRI launched a program to help nuclear plant operators make the transition from conventional, analog instrumentation and control systems to digital systems. This effort was prompted both by the increasing difficulty of finding replacement parts for analog equipment and by the benefits offered by the flexible and highly reliable digital technology.

The first step in the EPRI program was the development of a digital feedwater control system for the Monticello boiling water reactor of Northern States Power. This project marked the first major digital replacement of a control system at a U.S. nuclear plant. Technical risk was limited by retaining the existing three-element control logic while implementing its functions in digital hardware and software. In addition, dual-redundant microprocessors and a fault-tolerant design were used to improve control system reliability. Subsequently, EPRI participated in similar efforts at Northern States' Prairie Island pressurized water reactor (PWR) units. In each of these projects, the use of state-of-the-art distributed-control products increased fault tolerance and modularity while reducing implementation costs.

In addition to sponsoring projects emphasizing integration and demonstration, EPRI has pursued many specialized research projects in support of high-reliability nuclear plant control systems. These have included the development of parity-space software methods for improving tolerance to degraded or failed signals; methods for comparing alternative redundant-hardware architectures; and verification and validation methodologies for digital monitoring and control systems.

EPRI is now pursuing the logical next step in its long-term program: development of an advanced control system (ACS) that uses state-of-the-art digital hardware and software to forge a highly reliable and tightly integrated plantwide control system. This effort involves a three-year tailored-collaboration agreement with five member utilities of the Babcock &

Wilcox Owners Group (BWOG)—Arkansas Power & Light Company (of Entergy Corporation), Duke Power Company, Florida Power Corporation, GPU Nuclear Corporation, and Toledo Edison Company. The goal is to complete the development and testing of a prototype ACS that will improve the operational flexibility and trip avoidance of B&W PWRs.

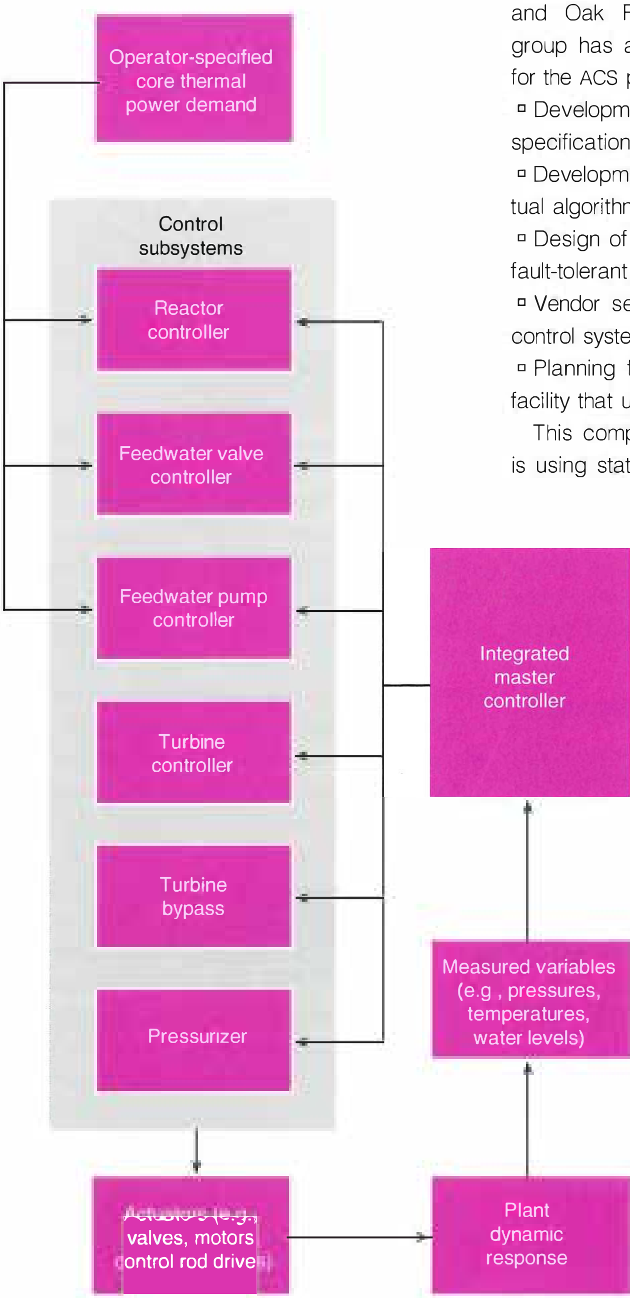


Figure 1 The advanced control system must coordinate major systems and support systems to maintain energy and mass balances during transient events. The integrated master controller, the heart of the system, uses a complex control algorithm to anticipate imbalances and speed the return to a steady state.

A BWOG task force has been actively developing an ACS for several years. Working with Babcock & Wilcox Nuclear Service Company and Oak Ridge National Laboratory, the group has accomplished several objectives for the ACS prototype:

- Development of requirements and design specifications
- Development and validation of a conceptual algorithm for control
- Design of a hardware configuration and a fault-tolerant architecture
- Vendor selection and the procurement of control system hardware
- Planning for a "hardware-in-the-loop" test facility that uses a training simulator

This comprehensive utility-managed effort is using state-of-the art computer hardware, software, and simulation and testing technology. In joining forces with utilities with B&W PWRs, EPRI recognizes the value of this experience to other member utilities that may launch similar programs for upgrading control systems. Furthermore, the ACS will give EPRI member utilities an opportunity to acquire experience with a level of complexity higher than that of previous demonstrations.

ACS characteristics and design

The ACS will control and coordinate the following major systems: the reactor coolant system (RCS), the steam generators, the feedwater and condensate system, the steam system, and the turbine generator system. It will also coordinate support systems for RCS pressure control, RCS inventory control, and decay heat removal.

The key project goal is to devise a control system that avoids trips for a wide range of transient events and signal failures and that increases operational flexibility by removing unnecessary conservatism from operating margins. Meeting this objective requires the tight coordination of controlled responses in order to maintain energy and mass balances during transient events. For example, the pressurizer pressure is sensitive to the primary-system temperature, which in turn depends on the balance between the reactor thermal power and the heat transferred through the steam generators. The steam generator heat transfer and the thermal power delivered by steam flow to the turbine and bypass must be precisely balanced in order to maintain a stable steam pressure.

This tight coordination of several systems requires the use of both feedback logic and feedforward logic incorporating models of plant dynamics. In addition, the control system must accommodate various operating modes and interlocks and must account for the margins to trip. A complex algorithm is necessary to meet these requirements. Moreover, tightly coupled control magnifies the importance of fault tolerance to prevent the failure of one sensor or computer component from causing imbalances throughout the plant.

Figure 1 illustrates the conceptual design of the ACS in a fully automatic mode. The control room operator sets an overall demand for thermal power, which immediately adjusts set points in the reactor and feedwater control subsystems. Control of feedwater to the two steam generators is adjusted independently to accommodate such asymmetries as reduced pump operation or tube fouling. The control subsystems send signals to adjust actuators like control valves, control rod drives, and pumps.

The heart of the ACS is the integrated master controller (IMC), which takes input measurements of key process parameters and determines the demand values for key controlled variables, such as feedwater flows, reactor coolant flow, and reactor power. Attaining this set of consistent demand values guarantees that important mass and energy balances are maintained throughout the system. The IMC algorithm may use feedforward logic to anticipate imbalances, to accelerate their suppression, and to speed the return to a steady state. These demand signals travel to the individual control subsystems that handle the local control of actuators.

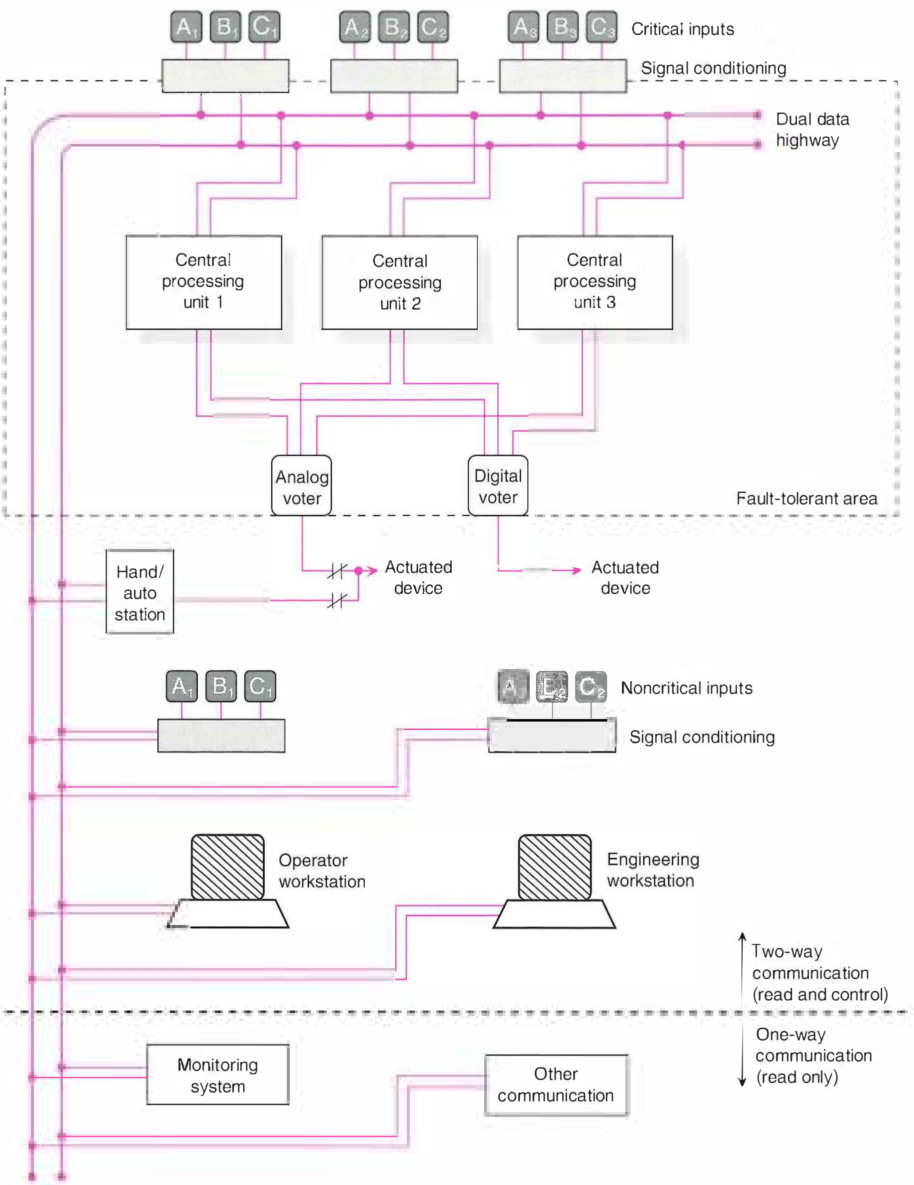
Through hand/auto stations, the control room operator can override the automatic control of any system. If one or more of the systems are under manual control, the ACS enters a tracking mode, in which the automatically controlled variables follow, or "track," the manually controlled process variables in order to maintain the energy balance.

A triple modular redundant architecture ensures high reliability in the ACS (Figure 2). Using voting logic, the architecture eliminates any one faulty signal out of three without interrupting control signals. The system is also insensitive to the failure of a single computer component, such as a central processing unit, a bus, or a communications module.

Design studies have identified the critical input signals whose failure during operational transient events may lead to a plant trip. These critical signals follow triply redundant paths. The analog and digital output signals from the three redundant central processing units are voted on before being passed to the actuators, which ensures highly reliable control signals. To reduce the complexity and cost of the system, a dual-redundant configuration handles noncritical input signals.

The ACS designers have selected specific commercial lines of hardware for the distributed control system and the voter. However, a utility could use competing products to implement the generic architecture shown in Figure 2.

Figure 2 The ACS fault-tolerant architecture builds in high reliability through redundant signal paths and components. It also uses voting logic to eliminate faulty signals without interrupting control signals.



The design process

Because of the IMC's interactions with subsystem controllers and because of the hardware and software features necessary to support the fault-tolerant design, the ACS is a highly sophisticated system. Therefore, a systematic design, verification, and validation process is essential to ensure the adequacy of its design and implementation. The ACS project team is pursuing three closely interrelated tasks: overall design and integration, development of the control algorithm, and simulator-based testing and validation.

The participating utilities began by developing a set of requirements for control system performance and features. These requirements governed the definition of a general hardware architecture and the selection of hardware vendors.

Because of the complexity of the control system algorithm, the project team first developed it conceptually in a prototyping software environment that allowed efficient evaluation of trade-offs and tests. The power plant simulation environment employed was the Modular Modeling System, developed by EPRI and commercialized by Babcock & Wilcox Nuclear Service Company. The algorithm equations were rewritten in a standard SAMA (Scientific Apparatus Makers Association) diagram format to allow easy implementation on a modern control system delivery platform.

The test program will use a full-scale training plant simulator, with important software modifications to enable simulation of the specific participating plants. The ACS hardware and software will be linked to the simulator test facility. The simulator will supply process variables to the ACS, which in turn will evaluate the control signals to be passed back to the simulator. This hardware-in-the-loop approach to testing will provide a comprehensive test of the ACS in a realistic plant environment and will greatly simplify preinstallation verification and validation.

This state-of-the-art project will demonstrate the full potential of digital control in nuclear power plants, paving the way for a smooth transition from aging analog systems to modern digital technology. The experience and documentation provided by the ACS project will give EPRI member utilities a comprehensive base of knowledge for implementing large-scale digital control system replacement efforts in their nuclear power plants.

Air Quality

Air Toxics Risk Analysis

by Leonard Levin, Environment Division

Several factors, including increased public concern, recent regulatory actions, and improved technical tools, are boosting interest in evaluating hazardous air pollutants. In particular, the 1990 passage of new amendments to the federal Clean Air Act has focused attention not only on the sulfur and nitrogen oxides implicated in acid rain, but also on 190 substances that the legislation designates as hazardous pollutants. These so-called air toxics include heavy metals and organic compounds in both particulate and gaseous forms. Some of the substances cited occur in trace quantities in fossil fuels or are formed during combustion in power plant boilers.

For nearly a decade, EPRI has focused on air toxics risk analysis as part of its work to assess the potential health consequences of utility operations. As a result, the use of sophisticated EPRI-developed analytical methods and models is widespread in the utility industry. Now that Congress has charged the Environmental Protection Agency with conducting a three-year study to determine whether air toxics from power plants represent a threat to public health, a new imperative exists in the industry to develop reliable data. In response, EPRI is updating two widely used computer tools and introducing a third to help managers make informed decisions as they seek to meet changing regulatory requirements. The Institute has also begun a major effort to synthesize risk information for use by researchers and regulators.

Research objectives

EPRI air toxics risk research has several objectives:

- To help utilities meet explicit regulatory requirements for air toxics risk assessments at the national, state, and local levels
- To supply tools that allow utilities to assess the health risks of potential changes in operations in light of environmental regulations
- To provide the scientific data decision makers need to develop technically sound power plant regulations
- To develop new and more-accurate ways to perform risk assessments

As it pursues these objectives, EPRI's air toxics risk research is exploring a number of key questions:

- In what quantities do utility power plants emit individual substances or groups of substances?
- What are the risks associated with these utility emissions?
- Which utility source types or individual sources can be shown to have lower calculated health risks?
- How will controls or operating changes affect air toxics emissions and risks over time?
- What research objectives should the utility industry pursue in the next few years?

To answer such questions, EPRI researchers are expanding the arsenal of planning tools and scientific data available to both utilities and the research community. For example, new versions of AERAM (the Air Emissions Risk Assessment Model) and AirTox, to be released this year, will provide a quick, easy way for utilities to evaluate possible changes in plant operations or fuel use and determine their effects on emissions of hazardous air pollutants.

Whereas these models provide information about the health risks of inhaling potentially toxic air emissions, EPRI researchers also are developing a tool to allow utilities and regulators to evaluate a broader range of health risks from chemical exposures. The new methodology, RiskPISCES, will be available later this year. It will assess a variety of gaseous, liquid, and solid power plant discharges that might pose health threats through inhalation, ingestion, direct skin contact, or other exposure routes.

In addition, to help regulators establish technically sound environmental guidelines concerning health risks specifically from utility sources and to provide guidance to the research community, EPRI recently began a broad synthesis of risk information known as the Comprehensive Risk Evaluation, or CORE. This effort is scheduled for completion in 1993.

AERAM

The keystone of EPRI's risk analysis framework, AERAM evaluates human health risks from power plant operations for particular plant configurations. Using individual power plant data, the model performs risk assessments for discrete operating scenarios. In each case, it evaluates the health risks of toxics that disperse into the atmosphere.

A dozen utilities and utility groups nationwide have used AERAM since its introduction in 1983. EPRI researchers foresee that in its new, user-friendly version (2.01), the program could benefit every utility likely to build new facilities or modify existing ones. Now in the final stages of development, AERAM 2.01, which runs on MS-DOS systems, greatly reduces the data-gathering requirements that often make environmental models cumbersome to use. The result is an extremely cost-effective model that can quickly compute the information managers need to make informed planning decisions. Users can review alternative cases without investing large amounts of staff or consultant time.

Earlier versions of AERAM focused on emissions from coal-fired power plants; Version 2.01 will include modules that allow users to study oil-fired operations and alternative fuels without the need for additional model development. This enhancement responds to recent findings that some oil-fired plants might emit significant amounts of air toxics, depending on their design.

AERAM 2.01 has greatly improved graphic display capabilities. Users can easily create eye-catching three-dimensional graphs to plot such study results as exposures and concentrations.

ABSTRACT *New regulations and heightened public concern have increased the need to understand and communicate information about hazardous air pollutants and human health risks. EPRI's work in air toxics risk analysis is providing utilities with flexible, efficient ways to analyze toxics control alternatives. Upgrades of two widely used computer models—AERAM and AirTox—will offer user-friendly, cost-effective tools for evaluating the risk consequences of changes in utility operations and fuel use. In addition, a new methodology called RiskPISCES will soon be available to help utilities meet emerging requirements for multimedia risk assessments. And to present a broad analysis of the issue to the industry, EPRI has recently launched a comprehensive risk evaluation and data synthesis project.*

AirTox

To evaluate a wide range of "what if" scenarios, data from AERAM 2.01 can be input into AirTox, available soon in Version 2, so that the two programs run in tandem. Whereas AERAM is a useful risk assessment tool for exploring a limited number of operating modes, AirTox is a risk management tool that allows utilities to consider the risk consequences of a variety of options (Figure 1).

The new link between the two programs makes both more cost-effective and quicker to use. Taking data from AERAM as a base case, AirTox users can easily manipulate parameters to determine the health risk effects of changes in fuel, stack height, or other key operating features. AirTox also allows users to assess the costs of alternative operations on the basis of data from utility engineers and vendors.

In addition, AirTox expands on AERAM's capabilities by allowing utilities to explicitly incorporate uncertainties concerning such factors as emissions rates, control efficiencies, and the relationship between exposure and health effects. AirTox can help a utility gain perspective on its contribution to air toxics exposures in the local environment, explore trade-offs between acting soon and waiting for key research results, and evaluate the implications of changes in emissions levels over time.

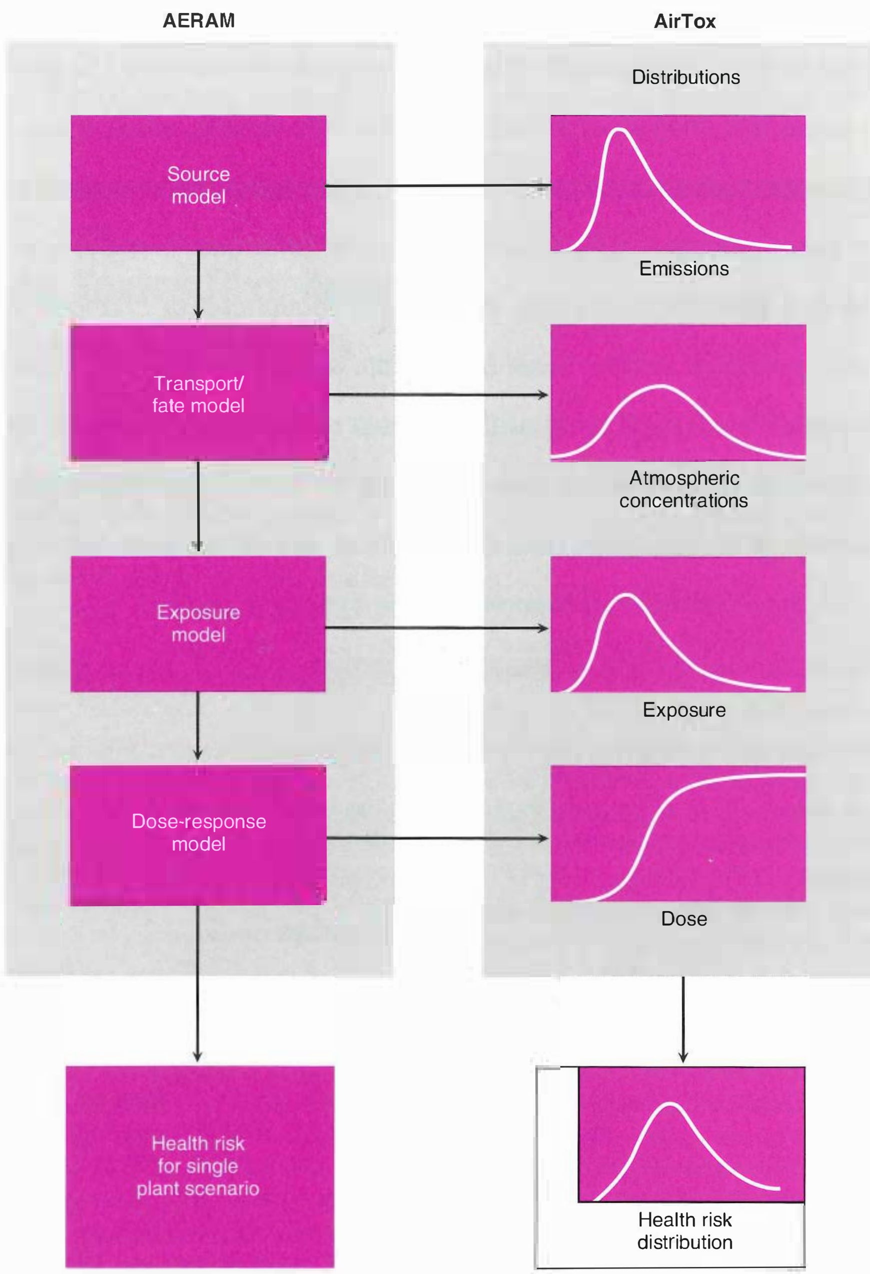
Other improvements in AirTox 2 include new tutorial and help screens. By providing more-specific guidance on data entry, researchers have made the program easier to use. Together, the new versions of AERAM and AirTox provide an important tool kit to help utilities assess potential health risks from air toxics emissions and gain insight into the risk trade-offs of additional emissions controls.

RiskPISCES

Though most air toxics risk research to date has focused on the inhalation pathway of human exposure, recent findings indicate that other means of exposure—for example, through groundwater, skin contact, or food chain transfers—may be equally significant. Certain environmental toxics, such as mercury, enter the human body only through noninhalation routes. For utilities that want to consider liquid and solid discharges as well as gaseous emissions and to explore several potential pathways for human exposure, RiskPISCES will provide an excellent tool.

Now in the final stages of development, RiskPISCES will help utilities satisfy recent state and local requirements for multimedia risk assessments to meet air quality stan-

Figure 1 Utilities can use AERAM and AirTox to perform a full range of air toxics risk assessments, from preliminary screening studies to detailed probabilistic analyses. AERAM incorporates detailed physical process models that use plant-specific data to determine the health risk for a single scenario. Using results from multiple AERAM runs, AirTox can examine the impact of important uncertainties in data and assumptions.



dards. Given that federal and state regulators are considering additional steps of this sort, the new methodology will provide a consistent framework for utilities to meet a broad range of regulatory demands.

RiskPISCES initially will consider key air toxics that EPRI's PISCES (Power Plant Integrated Systems: Chemical Emissions Study) project has identified in fossil power plant flue gas. These chemicals are among the 190 compounds designated as hazardous air pollutants by the recent clean air legislation.

The model uses sensitivity analyses to evaluate which exposure pathways are of greatest concern for each substance and each setting. Risks that merit further concern can then be explored in greater detail. In addition to assessing cancer risk, RiskPISCES can be used to develop measures of risk for subtle, difficult-to-assess noncancerous effects—for example, for toxics believed to cause neurological disorders.

Because of its complexity, RiskPISCES has extensive data requirements. As a result, additional interfaces and default data sets may have to be developed before utility personnel can use the model directly. Initially, RiskPISCES will be available to EPRI members for case studies in which EPRI researchers and utility staffers collaborate.

CORE

EPRI researchers, with the cooperation of the Utility Air Regulatory Group, recently began the Comprehensive Risk Evaluation, a three-year study to synthesize information from individual power plant air toxics risk assessments. CORE will put these past risk assessments on a consistent footing in an attempt to draw broad conclusions about hazardous air pollutants that may apply throughout the electric power industry.

By identifying areas where further research is necessary to reduce uncertainties in risk assessments, the CORE results will help guide future health and environmental studies and will support the planning of utility emissions control options. In addition, the findings will help inform the national agenda by giving regulators sound technical information on which to base future decisions.

Scheduled for completion in 1993, CORE will identify classes of power plants that may pose potentially large health risks under the standards expected to be adopted by regulators, as well as those classes likely to be of little concern from a health risk perspective. Other work is examining basic power plant combustion chemistry to determine which of the 190 compounds cited in the clean air legislation are likely to be present in utility emissions. CORE researchers also will assess whether the hazardous air pollutants considered in PISCES and RiskPISCES are the most important ones to investigate in terms of health risk consequences. Further, proposed emissions controls for sulfur dioxide and nitrogen oxides will be studied to determine their impact on overall plant emissions of toxics. Specifically, researchers will investigate the impact of reduced air emissions on total toxic releases as a result of the transfer of toxics from stack emissions to water and solid discharges.

To carry out these studies, CORE is drawing on research from throughout EPRI and across the utility industry. Project results from the Generation and Storage Division and the Integrated Energy Systems Division are being incorporated into CORE analysis scenarios of industry operations and future power plant configurations. Results of risk analyses conducted by individual utilities without EPRI involvement are being included in the data set. As these results come in and are integrated into the evaluation, CORE will yield new insights for utilities and researchers on the potential impacts of hazardous air pollutants.

Land and Water Quality

Leaching Chemistry of Combustion By-products

by Ishwar P. Murarka and Adda Quinn, Environment Division

Public concern about solid waste and groundwater issues rose steadily in the 1980s, as evidenced by the proliferation of state and federal regulations governing the handling and land disposal of solid waste. These concerns directly affect the high-volume by-products generated by burning coal and oil for electricity. The electric utility industry produced approximately 90 million tons of combustion by-products in 1989, consisting principally of fly ash, bottom ash, slag, and flue gas desulfurization (FGD) sludge. Currently, about 20–25% of this material is utilized, and the remaining 75–80% is disposed of in landfills or surface impoundments. The total volume of by-products generated is expected to double in the next two decades, owing to an increased demand for electricity and to the enhanced flue gas scrubbing required by the recently passed Clean Air Act amendments.

In 1982, EPRI initiated a research effort—the Solid Waste Environmental Studies (SWES)—to address utility solid waste management and groundwater protection issues (RP2485). A primary goal of SWES is to integrate complex research results into userfriendly tools that utilities can use to predict the leaching, attenuation, transport, and environmental fate of inorganic chemicals associated with combustion by-products in disposal and utilization settings. SWES addresses five major areas:

- Leaching chemistry
- Chemical attenuation
- Subsurface dispersion
- Model development and validation
- Field sampling and data evaluation methods

This article focuses on leaching chemistry. Researchers in this area are describing leaching reactions in laboratory experiments, observing leaching processes under field conditions, and integrating the results into predictive models. Recent work has led to significant improvements in the Fossil Fuel Combustion Waste Leaching (FOWL™) code, initially released in 1988 (EPRI report EA-5742-CCM). In addition, field studies have assessed leaching dynamics at a wet disposal facility and evaluated the formation and release of hydrogen sulfide (H_2S) gas at an FGD waste disposal site.

Improved leachate prediction

FOWL 1.0 was developed to translate leaching geochemistry research into a model that utilities could use to predict the mobilization and release of inorganic chemicals from combustion by-products. The new version (2.0), to be released by July of this year, includes several enhancements that make it possible to more accurately predict the aqueous concentrations, quantities, and release durations of leachates produced at utility sites.

FOWL 2.0, which runs on IBM PCs and compatible computers, consists of five modules. The input and output modules are designed to be flexible and easy to use. The input module is used to specify by-product type, to modify the default by-product characteristics (if necessary), and to enter site-specific data on a facility's physical and hydrologic characteristics. The output module gives aqueous concentrations and leachate quantities as a function of time, in both tabular and graphic form.

Leachate quality and quantity are calculated in the geochemical module and the water balance module, respectively. One of the most significant model enhancements was the addition of GMIN, a new geochemical equilibrium code that draws on the extensive thermodynamic and empirical data amassed from five years of laboratory and field research under SWES. The expanded and improved thermodynamic database makes possible the mechanistic prediction of aqueous concentrations for 10 elements on the basis of known solid phases: Ba, Ca, Cd, Cr, Cu, Mo, Na, S, Sr, and Zn. Improved empirical relations are included for As, B, Ni, and Se, the few remaining elements for which a mechanistic understanding is still incomplete. FOWL's ability to calculate leachate quantities at both landfills and surface impoundments has been greatly improved through the incorporation of

ABSTRACT *EPRI's Solid Waste Environmental Studies (SWES) entail laboratory and field research on the fundamental processes governing the release and transport of inorganic chemicals from fossil fuel combustion by-products. Results have been successfully used by utilities and regulators to address groundwater protection issues in the management of by-product disposal and utilization. One SWES goal is to develop mechanistic models for predicting leachate composition, release rate, and release duration. Recent work has led to a better understanding of the leaching process, a better definition of leachate composition, and enhancements to the EPRI-developed leachate generation model FOWL. The improved model provides an accurate, easy-to-use tool for predicting the quantity and quality of leachate from combustion by-products.*

the Hydrologic Evaluation of Landfill Performance (HELP) code, developed by the U.S. Environmental Protection Agency (EPA). In addition, FOWL 2.0 contains new algorithms for the direct calculation of seepage rates from surface impoundments.

The main calculation module is the heart of FOWL 2.0. By coupling geochemical and hydrologic calculations, this module can make detailed predictions of leachate concentrations as a function of time. Sample output from a coupled calculation based on a typical midwestern disposal site is shown in Figure 1. Major element chemistry is initially influenced by leaching of the highly soluble sulfate salts, primarily Na_2SO_4. After the relatively rapid removal of the readily soluble Na and SO_4, long-term Ca and SO_4 concentrations stabilize and are controlled by gypsum ($CaSO_4 \cdot 2H_2O$) dissolution.

Trace element chemistry, which is highly dependent on pH, is generally more complex than major element chemistry. In the example shown in Figure 1, the Zn concentration is controlled by ZnO dissolution and increases significantly over time as a result of the decreasing pH. Conversely, the Cd concentration is controlled by the relatively insoluble $CdCO_3$ and is consistently low.

Field data from four Pennsylvania ash disposal sites were used to develop a new method to more accurately predict concentration on the basis of the relationship between SO_4 and electrical conductivity. Comparison of predicted concentrations with field measurements indicated that FOWL 1.0 consistently underpredicted SO_4 by a factor of 2–5. The principal cause of the underprediction involved highly soluble Na and Mg sulfate salts found in fresh ash during the initial leaching period (when 1–2 pore volumes of water moved through the ash). Inaccurate thermodynamic constants for a few sulfate-bearing solids also contributed to the underprediction. FOWL 2.0 incorporates a functional relationship between electrical conductivity and sulfate concentration for the early leaching period, along with improved thermodynamic data for gypsum ($CaSO_4 \cdot 2H_2O$), barite ($BaSO_4$), and celestite ($SrSO_4$) solids. As a result, there is now very good agreement between predicted and observed concentrations for Ca, SO_4, Sr, and Ba. Figure 2 shows comparisons for Ca and SO_4.

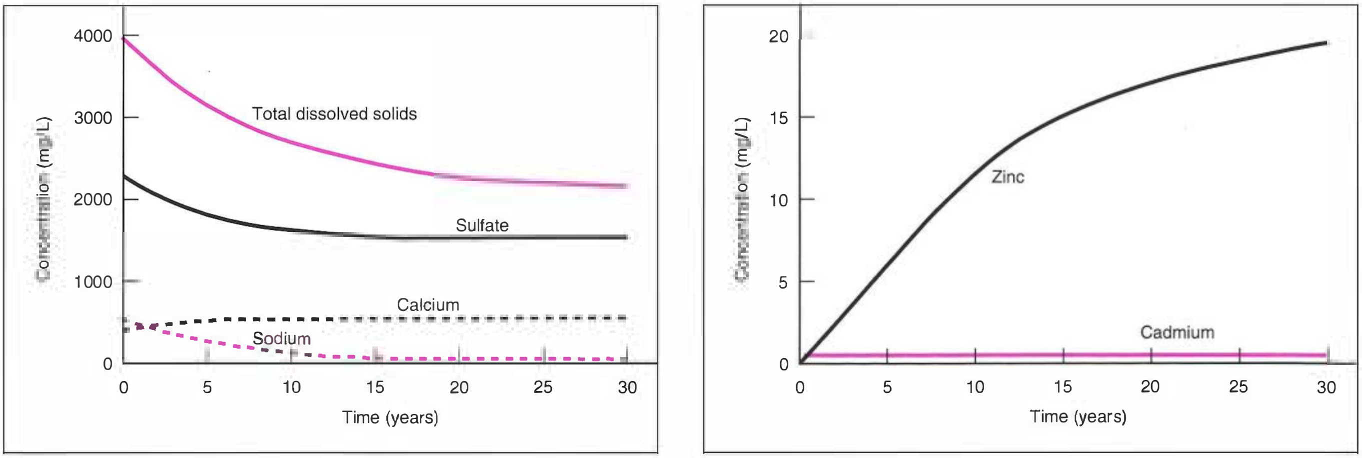
In designing new facilities or remediation studies, the accurate prediction of leachate quantities is critical to the development of strategies to minimize leachate generation. Ongoing laboratory research in leaching geochemistry is focused on the identification of mineral phases that control the equilibrium geochemistry of trace metals, and on the verification of leachate predictions with field data. This information will be used to augment the thermodynamic and empirical databases in FOWL 2.0.

Sluice pond field study

The method of by-product utilization, storage, or disposal has an important influence on the rate of leaching and release to the environment. In 1990, EPRI initiated a field study on active and inactive sluice ponds at a Kentucky power plant to gauge the leaching dynamics in a wet system and to identify the factors controlling short-term and long-term releases. Previous SWES field studies had considered leaching dynamics at a dry landfill (EA-5922), an inactive FGD sludge site (EA-5923), and two coal ash utilization sites (EN-6532, EN-6533); at all these sites the primary leaching fluid was rainfall, and it could therefore take several years for a single pore volume of water to move through the by-product material.

At the wet disposal site in Kentucky, researchers observed dramatic fluctuations in short-term leachate quality as a function of the type of ash being sluiced (Figure 3). Sluice water transporting fly ash fines that had been collected in an electrostatic precipitator had significantly lower pH levels and higher dissolved solids than sluice water transporting cyclone ash or bottom ash. Concentrations of several trace elements (As, B, Cr, Co, Cu, V, Zn) were higher by as much as a factor of 10

Figure 1 The improved FOWL code was used to calculate concentrations of selected major (left) and trace (right) dissolved leachate components at a typical midwestern coal ash disposal site. The code couples geochemical and hydrologic calculations to make possible detailed predictions like these.



in sluice water carrying precipitator ash. The higher levels resulted in part from increased dissolution/desorption due to the lower-pH (higher-acidity) environment created by the sulfuric acid associated with the smaller fly ash particles.

The long-term leachate composition is dictated by the sluice water's solid-to-solution ratio (1:20), which facilitates rapid solubilization and mixing of most of the ash's readily leachable major and trace elements. As a result, lesser amounts of soluble constituents (B, Ca, SO_4) are available for long-term leaching. Once the ash-bearing water is released to the pond, concentrations of some trace elements appear to be attenuated by precipitation and adsorption reactions within the ponded ash—reactions resulting from changes in pH and other environmental variables. Thus the release of these elements to the environment is further limited.

The study also suggests that, at least at this site, efforts to control short-term leachate production could concentrate on management of the precipitator ash, which represented only about 20% of the total volume but was the primary source of acidity and dissolved metal loadings to the pond.

FGD sludge field study

FGD wastes present special challenges affecting overall chemical releases from disposal facilities. One such problem is the for-

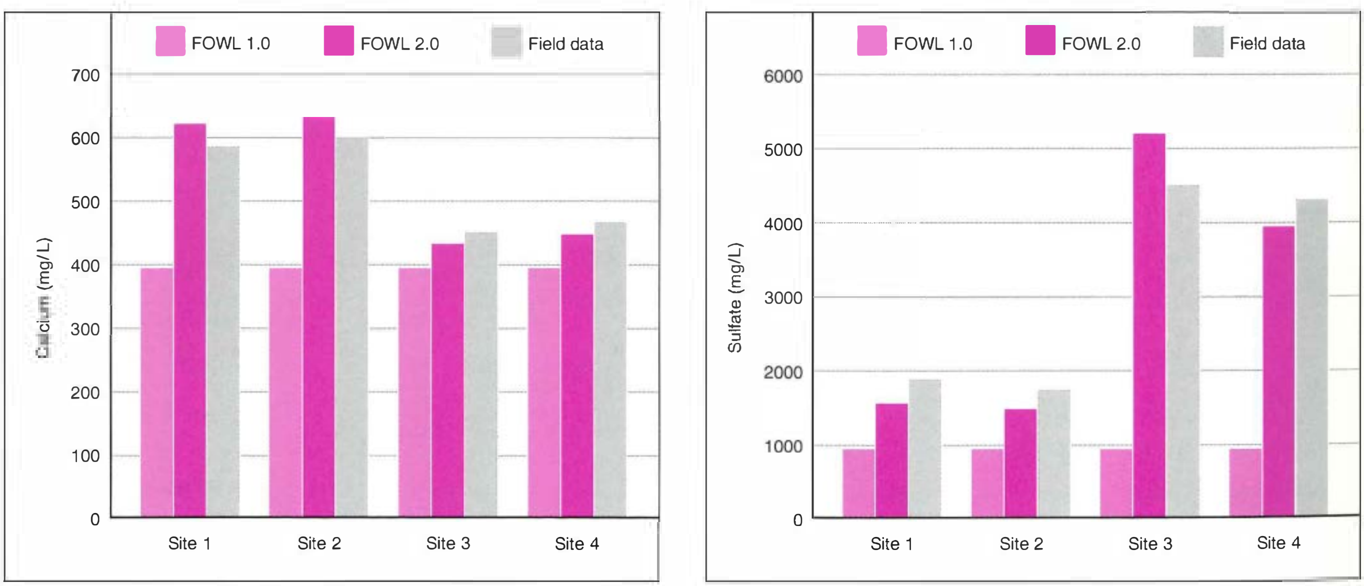


Figure 2 Measured and predicted concentrations of calcium (left) and sulfate (right) at four Pennsylvania coal ash disposal sites. FOWL 2.0 uses information on the relationship between sulfate and electrical conductivity, as well as improved thermodynamic data, to yield more-accurate calculations.

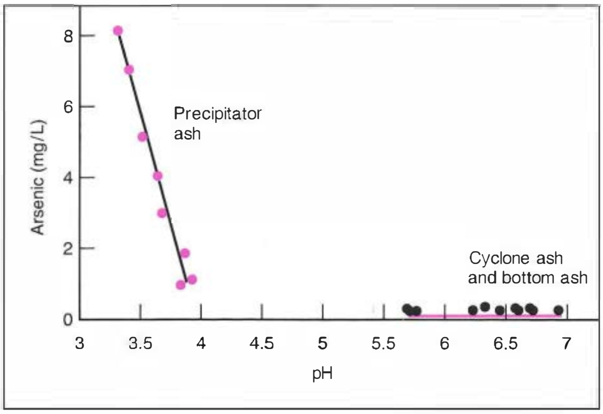


Figure 3 Data from a wet disposal site have revealed dramatic differences in short-term leachate quality as a result of the type of ash being sluiced. The lower pH associated with precipitator ash is one factor in the higher levels of arsenic and other trace elements observed in leachates produced by that ash.

mation of hydrogen sulfide (H_2S) gas and its emission from an FGD sludge pond surface. To investigate H_2S formation and release, a field study was initiated at a power plant with two FGD sludge ponds. Pond 1 received only FGD wastes from a single-pass sodium carbonate scrubber and had a history of periodic H_2S emissions; pond 2 received fly ash codisposed with FGD wastes from a Venturi-type scrubber and had no H_2S emission problems.

H_2S production occurred in the bottom sediments of both ponds, where there was a suitable substrate for sulfate-reducing organisms. In pond 1, the release of H_2S from the sediments was restricted by a sodium sulfate crust on the pond bottom; as a result, the gas was concentrated and was periodically released through cracks or open areas in the crust. Once released, the H_2S traveled essentially unaltered through the shallow, oxygen-depleted water column and escaped at the pond surface. The water column and sediments had high concentrations of reduced sulfur species (sulfite, thiosulfate, and sulfide) that helped maintain anoxic conditions by completely consuming available oxygen. Conversely, at pond 2 there was no bottom crust to concentrate H_2S, and the water column was oxic. Researchers hypothesized that the release of H_2S formed in the pond 2 sediments was mitigated by precipitation of metal sulfides (e.g., FeS, CuS, ZnS) within the sediments and by oxidation within the water column. The metals were supplied by the codisposed fly ash.

Resampling of the ponds after one year showed that both ponds emitted H_2S gas. Apparently the finite oxidizing capacity of pond 2 was exhausted through the continuous generation of H_2S by microbial activity in the pond sediments. Knowledge of H_2S sources and migration paths can be used to identify potential control strategies. For example, removal of the reduced sulfur species that may compete for oxygen in the water column appears to be an important factor in maintaining an oxidizing environment in the pond. Interim measures now employed to control H_2S emissions at this site consist of using hydrogen peroxide and aeration to oxidize the reduced sulfur species.

SWES benefits

Over the past 10 years, the SWES leaching research has provided extensive laboratory and field data to formulate a basic understanding of the leaching behavior of combustion by-products. The utility industry has reaped substantial benefits from the SWES results. For example, the EPA's 1988 report to Congress relied heavily on SWES research in finding that coal ash should not be regulated as a hazardous waste. Pending regulations for coal combustion waste disposal and the reauthorization of the Resource Conservation and Recovery Act will heighten the need for additional information over the next few years.

FOWL 2.0 makes the results of the leaching research accessible to utilities in an easy-to-use form. Ongoing work will continue to refine and add to the existing database through several field studies. Limited laboratory experiments will be used to clarify the time-dependent reaction kinetics and source depletion rates affecting long-term leaching. Information from the field and laboratory studies will be integrated to further improve FOWL's predictive capabilities. Future work will target specific utility issues, such as the generation of leachate from by-products of combustion with the newest emissions control technologies.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Development and Commercialization of Power Tools With Advanced Motors, Power Electronics, and Packaging (RP3087-10)	$99,400 15 months	Black & Decker Corp./ *B. Banerjee*
Design and Evaluation of Converter-Optimized Synchronous Reluctance Motor Drives (RP3087-12)	$301,100 18 months	University of Wisconsin, Madison/*B. Banerjee*
Comparing Emission Rates of Electric and Fossil Fuel End-Use Technologies (RP3121-3)	$90,700 7 months	Strategic Decisions Group/*P. Hanser*
Electric Vehicle Infrastructure: Customer Service Development and Support (RP3272-2)	$347,700 18 months	Hart, McMurphy & Parks/ *L. O'Connell*
Thermal Storage System Applications (RP3280-1)	$70,700 8 months	Denkmann Thermal Storage/*R. Wendland*
Electric Vehicle Infrastructure: Technical Development and Support (RP3304-1)	$206,100 12 months	Hart, McMurphy & Parks/ *L. O'Connell*
Test and Demonstration of EPRI's Commercial Needs-Based Segmentation Framework (RP3310-1)	$400,000 10 months	National Analysts/ *T. Henneberger*
Environment		
Leukemia in Animals Exposed to 60-Hz Magnetic Fields: Large Granular Lymphotic Leukemia Cell Transplant Model (RP2965-16)	$642,700 22 months	Battelle, Pacific Northwest Laboratories/*C. Rafferty*
Reactions Producing Water-Soluble Atmospheric Mercury (RP3218-1)	$509,000 32 months	Brooks Rand/*D. Porcella*
Numerical Laboratory Services for Model Evaluation Consortium for Climate Assessment (MECCA) (RP3267-1)	$2,000,000 17 months	University Corp. for Atmospheric Research/ *C. Hakkarinen*
Exploratory and Applied Research		
Neural Network Controllers for Combustion Systems (RP8005-13)	$101,000 11 months	PSI Technology Co./ *A. Mehta*
Novel Concepts for Heat Transfer Enhancement: Application of Ferrofluids in Oscillating Magnetic Fields (RP8006-20)	$168,100 12 months	Energy International/ *J. Maulbetsch*
Vector Processor Superconductor: Application to Power System Analysis (RP8010-20)	$150,000 21 months	University of Minnesota/ *D. Maratukulam*
Bacterial Cadmium Resistance: Potential for Bioremediation (RP8011-7)	$210,000 39 months	University of Illinois/ *R. Goldstein*
Vegetation Ecotones: Sensitive Landscape Measures for Effects of Global Change (RP8011-8)	$168,100 24 months	Applied Biomathematics/ *L. Pitelka*
Nuclear Reactions in Cold Fusion (RP8012-4)	$167,900 14 months	Texas A&M Research Foundation/*D. Worledge*
Fusion-Supporting Studies (RP8012-9)	$58,600 14 months	Rockwell International Corp./*T. Schneider*
Generation and Storage		
C-QUEL Development of a System to Apply Real-Time Coal Quality Information to Utility Operations (RP3123-6)	$338,200 33 months	Black & Veatch/ *D. O'Connor*
Coal Gasification–Based Power Coproduction Refineries (RP3226-4)	$303,300 13 months	Houston Lighting & Power Co./*M. Epstein*
Knowledge Base Development for Vibration Analysis of Combustion Turbines (RP3250-4)	$330,600 11 months	Southwest Research Institute/*G. Quentin*
Application Software Tool Kit for the SA·VANT Environment (RP3250-6)	$97,800 9 months	Sonoma Computer Integrators/*G. Quentin*
Thermal Performance Advisor for Gas Turbine Power Plants (RP3250-7)	$99,700 7 months	Enter Software/*G. Quentin*
Conversion of the EPRI Combustion Turbine Startup Advisor Expert System for Testing (RP3250-9)	$99,600 8 months	R&A Consulting Engineers/*G. Quentin*
Integrated Energy Systems		
Engineering and Economic Evaluation of Photovoltaic Power Plants (RP3273-3)	$242,400 9 months	Bechtel Group/ *C. McGowin*
Utility Responses to the 1990 Clean Air Act Amendments (RP3273-5)	$115,000 8 months	Energy Ventures Analysis/ *J. Platt*
Nuclear Power		
NMAC Prototype Interactive Computer-Based Maintenance Job Aid System (RP2814-39)	$79,900 9 months	General Physics Corp./ *J. Christie*
Maintenance Guide for Air-Operated Valves (RP2814-45)	$63,500 6 months	Fossil Technologies/ *K. Barry*
Melt Attack and Coolability Experiments (MACE) Program (RP3047-7)	$507,800 13 months	Argonne National Laboratory/*R. Sehgal*
Seismic Instrumentation of Power and Industrial Facilities in Mexico (RP3090-5)	$417,500 14 months	Centro de Instrumentación y Registro Sísmico/ *R. Kassawara*
Ulceration of the Skin Due to Discrete Radioactive Particles (RP3099-9)	$298,000 20 months	Texas Engineering Experiment Station/ *C. Hornibrook*
BWR Corrosion Control Software Package (RP3114-79)	$119,900 8 months	Altos Engineering Applications/*J. Haugh*
Resolution of Piping Issues (RP3114-82)	$149,500 8 months	Altos Engineering Applications/*B. Chexal*
High-Strength Alloys Replacement Advisor (RP3154-9)	$63,000 7 months	Decision Focus/*L. Nelson*
Residual Stress Measurements on Alloy 600 Weld Mockups (RP3223-2)	$92,700 7 months	Combustion Engineering/ *R. Pathania*
EPRIGEMS Module for FIVE Methodology (RP3234-1)	$98,300 7 months	Professional Loss Control/ *J. Sursock*
Advanced LWR, Phase 3: General Electric SBWR (RP3260-19)	$13,500,000 52 months	General Electric Co./ *R. Burke*
Hydrogen Water Chemistry Effect on Radiation Buildup (RP3313-1)	$96,500 10 months	General Electric Co./ *C. Wood*
NDE Qualification for Pressure Vessel Inspection (RP3348-1)	$1,197,600 11 months	J. A. Jones Applied Research Co./*S. Liu*
Limitorque Motor Operator Lubricant Development (RP3433-10)	$92,000 9 months	Bolt & Associates/ *J. Hosler*
Motor-Operated Valve Internal Component Database (RP3433-11)	$98,000 6 months	MPR Associates/*J. Hosler*
Evaluation of Zircaloys With Precious Metal Additions (RP3500-2)	$68,300 6 months	Teledyne, Wah Chang Div./*H. Ocken*
Influence of Roughness on Mass Transfer (RP3500-4)	$56,400 12 months	NEI International R&D Co./*B. Chexal*

New Technical Reports

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

CUSTOMER SYSTEMS

Commercial Lighting Efficiency Resource Book
CU-7427 Final Report (RP2285-20); $200
Contractors: Lighting Research Center; Hinge Group
EPRI Project Manager: K. Johnson

Water-Loop Heat Pump Systems: Assessment Study Update
CU-7535 Final Report (RP2480-2); $200
Contractor: Joseph A. Pietsch
EPRI Project Manager: M. Blatt

Customer Purchase Criteria for Small-Scale Cogeneration: A Historical Perspective
CU-7539 Final Report (RP2950-7); $200
Contractor: RCG/Hagler, Bailly, Inc.
EPRI Project Managers: W. LeBlanc, T. Henneberger

ELECTRICAL SYSTEMS

TLWorkstation™ Code, Version 2.0, Vol. 12: ROWPAK Manual
EL-6420 Final Report (RP2151-1); $200
Contractor: Power Technologies, Inc.
EPRI Project Manager: R. Kennon

Photovoltaic Generation Effects on Distribution Feeders, Vol. 2
EL-6754 Final Report (RP2838-1); $200
Contractor: New England Power Service Co.
EPRI Project Manager: W. Shula

Flexible AC Transmission Systems (FACTS): Scoping Study, Vol. 2, Part 1
EL-6943 Final Report (RP3022-2); $200
Contractor: General Electric Co.
EPRI Project Manager: D. Maratukulam

Effects of Geomagnetic Disturbances on Electric Power Transmission Systems
EL-7333 Final Report (RP2115-24); $200
Contractor: Georgia Institute of Technology
EPRI Project Manager: M. Rabinowitz

ENVIRONMENT

The Concept of Target and Critical Loads
EN-7318 Topical Report (RP2799-1); $200
Contractor: Forestry/Soils Consulting
EPRI Project Managers: R. Goldstein, J. Huckabee

Models to Assess the Response of Vegetation to Global Change
EN-7366 Topical Report (RP2799-1); $200
Contractors: The Boyce Thompson Institute for Plant Research; Systech Engineering
EPRI Project Manager: R. Goldstein

EMDEX II System Documentation, Vols. 1 and 2
EN-7497 Final Report (RP799-16, RP2966-7); $200 each volume
Contractor: Enertech Consultants
EPRI Project Manager: S. Sussman

EXPLORATORY AND APPLIED RESEARCH

Proceedings: Workshop on Advanced Mathematics and Computer Science for Power Systems Analysis
EAR/EL-7107 Proceedings (RP8010); $200
Contractor: George Fegan & Associates
EPRI Project Managers: W. Esselman, R. Iveson

High-Temperature Corrosion Research in Progress
EAR-7433 Special Report (RP2426-10); $200
Contractor: University of Manchester Institute of Science and Technology
EPRI Project Manager: J. Stringer

GENERATION AND STORAGE

Coal Slurry Applications and Technology
GS-7209 Final Report (RP1895-33); $200
Contractor: Combustion Processes, Inc.
EPRI Project Manager: W. Weber

Feedwater Heater Survey
GS-7417 Final Report (RP1403-22); $200
Contractor: ABB Power Generation, Ltd.
EPRI Project Manager: J. Bartz

Proceedings: 15th Annual EPRI Conference on Fuel Science
GS-7434 Proceedings; $200
EPRI Project Manager: H. Lebowitz

Evaluation of a 2.5-MW Spray Dryer/Fabric Filter SO_2 Removal System
GS-7449 Final Report (RP1870-3); $200
Contractor: Radian Corp.
EPRI Project Managers: B. Toole-O'Neil, R. Rhudy

Compressed-Air Storage With Humidification (CASH) Coal Gasification Power Plant Investigation
GS-7453 Final Report (RP2834-1); $200
Contractor: Energy Storage and Power Consultants, Inc.
EPRI Project Managers: A. Cohn, B. Louks

Boiler Tube Failure Reduction Program
GS-7454 Final Report (RP1890-7); $200
Contractor: General Physics Corp.
EPRI Project Manager: B. Dooley

Pulse-Jet Baghouses: Users' Survey
GS-7457 Final Report (RP1129-21); $500
Contractor: Victor H. Belba
EPRI Project Manager: R. Chang

Cleanup Options: Organic-Contaminated Tailings, Vols. 1 and 2
GS-7465 Final Report (RP2655-22); $200 each volume
Contractor: Remediation Technologies, Inc.
EPRI Project Manager: S. Yunker

INTEGRATED ENERGY SYSTEMS

Central Appalachia: Production Potential of Low-Sulfur Coal, Vol. 1
IE-7116 Final Report (RP3199-2); $200
Contractor: Hill & Associates, Inc.
EPRI Project Manager: J. Platt

Central Appalachia: Coal Mine Productivity and Expansion
IE-7117 Final Report (RP3199-6); $200
Contractors: Pennsylvania State University; Resource Dynamics Corp.
EPRI Project Manager: J. Platt

NUCLEAR POWER

Seismic Verification of Nuclear Plant Equipment Anchorage (Revision 1)
NP-5228-M Final Report (RP2925-1); $200
Contractor: URS/John A. Blume & Associates, Engineers
EPRI Project Manager: R. Kassawara

Nuclear Plant Design and Modification Guidelines for PWR Steam Generator Reliability
NP-7380 Final Report (RPS307-13); $200
Contractor: GEBCO Engineering, Inc.
EPRI Project Manager: C. Welty

Preoperational Practices for Steam Generators and Secondary-System Components
NP-7381 Final Report (RPS307-13); $200
Contractor: GEBCO Engineering, Inc.
EPRI Project Manager: C. Welty

Design and Operating Guidelines for Nuclear Power Plant Condensers
NP-7382 Final Report (RPS307-13); $200
Contractor: GEBCO Engineering, Inc.
EPRI Project Manager: C. Welty

Design and Operating Guidelines for Condensate Polishers in Nuclear Power Plants
NP-7383 Final Report (RPS307-13); $200
Contractors: GEBCO Engineering, Inc.; NWT Corp.
EPRI Project Manager: C. Welty

CALENDAR

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

MARCH

17–18
Conference: Integrated Resource Planning
Atlanta, Georgia
Contact: Susan Bisetti, (415) 855-7919

19
On-site, Low-level Waste Storage
Orlando, Florida
Contact: Linda Nelson, (415) 855-2127

25–26
Workshop: Key Account Marketing With CLASSIFY-Plus
Dallas, Texas
Contact: Thom Henneberger, (415) 855-2885

27
EPRI-Stanford Symposium in Honor of Chauncey Starr's 80th Birthday: Energy, Risk, and the Environment
Stanford, California
Contact: Lori Adams, (415) 855-8763

APRIL

1–2
Workshop: Tools for Cost and Quality Management in the 1990s
Houston, Texas
Contact: Lew Rubin, (415) 855-2743

7–8
2d Annual EPRI-NMAC Conference and Technical Workshop
Charlotte, North Carolina
Contact: K. Huffman, (704) 547-6055

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

8–9
Workshop: Key Account Marketing With CLASSIFY-Plus
Location to be announced
Contact: Thom Henneberger, (415) 855-2885

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

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

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

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

MAY

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

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

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

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

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

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

JUNE

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

2–3
1992 FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

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

4–5
1992 FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

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

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

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

JULY

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

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

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

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

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

Authors and Articles


Mueller


Gluckman


Fortune


Platt


Stahlkopf


Hingorani


Young

Natural Gas for Utility Generation (page 4) was written by Taylor Moore, the *Journal*'s senior feature writer, with assistance from four members of EPRI's Integrated Energy Systems Division.

Howard Mueller is program manager for the Utility Planning Methods Center, which includes research activities in fuel supply forecasting and risk analysis. Mueller joined EPRI in 1982 after five years as an administrator with the State of Maryland Power Plant Siting Program, where he directed work in demand forecasting and system planning. Before that, he taught at the University of Cincinnati and worked as a research chemist for Armco Steel Corporation.

Michael Gluckman is the division director. He previously oversaw technical evaluation and strategic planning in EPRI's Generation and Storage Division. Gluckman joined the Institute in 1975 as a project manager in coal gasification research and assumed responsibility for engineering and economic evaluations in 1980. Previously he was an assistant professor at the City College of the City University of New York, and before that, he worked for the St. Regis Paper Company.

Jim Fortune is program manager for engineering and economic evaluations. He joined EPRI in 1989 after nearly 10 years with Virginia Power, where he served as an engineering project manager and the director of engineering. Earlier he was the manager of system mechanical analysis for Babcock & Wilcox Company.

Jeremy Platt is a senior project manager in the division. He was previously with the Generation and Storage Division and, before that, with the Environment Division. Since joining EPRI in 1974, Platt has managed studies in energy resource assessment, fuel supply and market forecasting, and utility fuel planning issues. ■

Winners Discover, Develop, and Deliver (page 16) was written by John Douglas, science writer, from interviews with the award winners and with **Karl Stahlkopf**, who was recently appointed director of EPRI's Electrical Systems Division.

Before assuming his current responsibilities, Stahlkopf directed the Nuclear Power Division's Safety and Reliability Department. Earlier, from 1980 to 1989, he headed that division's Systems and Materials Department. Stahlkopf came to EPRI in 1973 after seven years in the Navy, where he specialized in nuclear propulsion. A University of Wisconsin graduate, he also holds MS and PhD degrees in nuclear engineering from the University of California at Berkeley. ■

Connecting With Russian T&D (page 26) was written by Leslie Lamarre, *Journal* feature writer, with assistance from two research leaders in the Electrical Systems Division.

Narain Hingorani, vice president for electrical systems since 1986, previously headed the Transmission Department. He came to the Institute in 1974 after six years with the Bonneville Power Administration. Before that, he spent 11 years in research, teaching, and consulting on the faculties of three British universities. Hingorani has a BS degree in electrical engineering from the University of Baroda in India and MS and PhD degrees from the University of Manchester Institute of Science and Technology in England. In 1988, Hingorani was elected to the National Academy of Engineers.

Frank Young, executive engineer, is responsible for key program areas that require executive-level attention, including magnetic fields, ESWorkstations, exploratory research, and Utility Communications Architecture. He previously served as director of the Electrical Systems Division for nearly four years. Before that, he was EPRI's manager of strategic planning for 10 years. Young came to the Institute in 1975 after 20 years with Westinghouse Electric. He graduated in electrical engineering from Stanford University and earned an MS in the same field at the University of Pittsburgh. ■

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