# Constraints to Coal Supply

ELECTRIC POWER RESEARCH INSTITUTE

# EPRI JOURNAL

OCTOBER
1980

EPRI JOURNAL is published monthly, with the exception of combined issues in January/February and July/August, by the Electric Power Research Institute.

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





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

Cover: The object of the coal supply game is to get more coal from the ground to the power plants. Along the way there are challenges in coal exploration, mining, labor, transportation, and regulation.

EPRI JOURNAL

Volume 5, Number 8 October 1980

Editorial



Features



Departments



Technical Review

# Expanding Coal: Some Tough Decisions

There is a growing awareness that oil and natural gas, which fueled the economic growth of industrialized nations in the last three decades, will be in short supply for the rest of this century and beyond. More efficient use of energy will be an important insurance against fuel shortages. But coal and uranium will have to play dominant roles as transition fuels and probably important roles as fuels for the much longer run. The United States is fortunate in having large resources of coal. Plans to burn increasing amounts of coal directly in utility and industrial boilers are featured in the forecasts of our energy future. In some forecasts, coal is also an important source for synthetic gaseous and liquid fuels. Moreover, because of our large coal resource endowment, many industrial nations have initiated discussions about our exporting this fuel. The United States, Australia, the Republic of South Africa, Canada, Poland, the Soviet Union, and the People's Republic of China are viewed as the principal coal exporters.

Substantial expansions in the mining and transport of coal are implied in these projections of increasing domestic and export markets, from a doubling of current production by 1990 to a tripling or more by 2000. Such an increase, under 5% a year, has been judged as feasible in a number of analyses.

But a question of increasing importance is whether this large increase in coal can be mined, transported, and used in a way that shortages and bottlenecks do not occur. If coal is to become the principal fuel to meet increased energy use, the transition will have to occur smoothly lest we create constraints in our own and the world's economic systems.

The cover story in this month's *Journal* discusses some of the problems in transforming paper estimates of coal resources into a fuel delivered at the right time, ready to use, and priced attractively to the user. Although the article does not look further, there are additional problems in building and operating coal-using facilities, particularly utility power plants.

How can there be potential problems in the mining and transport of coal if the resource base is so large and if analyses indicate that the needed expansion can be accomplished? The problems revolve around decisions—decisions that must be made in a timely fashion by persons who are faced with large uncertainties. Some of these decisions are in the private sector, such as committing large resources to open a mine without the certainty of a buyer for the entire product or a decision to improve railbeds and order rolling stock by a railroad that may not see business materialize because of competing modes of transport. These decisions are also in the public sector, such as allowing a strip mine to open although the absolute success of reclaiming the land cannot be guaranteed or the licensing of a coal-fired power station even though the exact pollution impact cannot be ensured.

Our success in meeting the coal expansion requirements depends on our ability as a nation to make necessary decisions despite uncertainty and in an atmosphere of strong differences of opinion. During the last decade our faith in our own abilities has been shaken by an awakening awareness of the frailty of our environment and by the sudden change in our energy and economic course. The institutions to grapple with these resources are in place but have yet to work smoothly. Identification of the problems to be solved before we can mine and transport the needed coal will help us recognize the need to take action now.

René Malès
Director
Energy Analysis and Environment Division

## Authors and Articles

Increasingly important today is **Coal Supply: New Strategy for an Old Game** (page 6), marked by uncertainties and risks for everyone involved, from the exploration geologist to the coal buyer on the spot market. Nadine Lihach, *Journal* feature writer, explains why resolution will not be easy among the interdependent institutions of mining, government, labor, transportation, regulation, and marketing. The experience of coal users (with electric utilities predominant among them) will ultimately tell whether the supply challenge is met.

Thomas Browne, Jeremy Platt, and Edward Altouney, staff members of the Supply Program in EPRI's Energy Analysis and Environment Division, helped Lihach pinpoint the issues of most concern to utilities. Browne, a project manager for energy production resources since September 1974, was previously a principal economist with the New York State Public Service Commission and briefly headed the economics and statistics unit of that state's Emergency Fuel Office. Earlier, he was a senior analyst for six years with Foster Associates, Inc., in Washington, D.C. Browne holds a BS and an MS in mineral economics from Pennsylvania State University.

Jeremy Platt, an EPRI project manager since July 1974, specializes in geologic assessments of energy resources. He is a 1971 graduate of Harvard University, where he concentrated on economic geology, and he added an MS in geology at Stanford University in 1974.

Edward Altouney joined EPRI in February 1979, having been director of the water resources management program at SRI International for nearly two years and an SRI engineering economist for three years. Between 1958 and 1977, Altouney worked in water resources management for the National Oceanic and Atmospheric Administration, the Department of Interior, and the California Department of Water Resources. He holds a BS and a PhD in civil engineering from the University of Lyons and Stanford University and an MS in management from Stanford.

■

Uncertainty and risk for utilities are quickly apparent in planning for new generating facilities. Individuals ultimately resolve these issues, and increasingly they use new tools to simplify the decision-making process. **Models: A Resource for the Decision Maker** (page 13) discusses three examples that illustrate this new approach. Developed under EPRI sponsorship to aid the Institute in setting priorities for its R&D funds, these models are proving equally useful to utilities in allocating their capital outlays. Jenny Hopkinson, *Journal* feature writer, consulted with Stephen Peck, manager of the Systems Program in the Energy Analysis and Environment Division, in preparing this review, which reveals how modeling methodology itself has come to be an R&D product.

Peck came to EPRI in October 1976, having been an assistant professor of economics at the University of California at Berkeley since 1971, as well as a National Science Foundation investigator of technological innovations by electric utilities. Peck graduated in engineering from the University of Cambridge (England) and earned an MSc at London University. He subsequently received an MBA and a PhD in business economics at the University of Chicago.

■

When a two-car family outgrows long vacation trips in its big station wagon and needs an economical second car for daily stop-and-go commuting, the choice is clear: trade for a subcompact model. When a utility's changing demand pattern calls for daily cycling of a big coal-fired generating unit, no such trade-in option exists.

**Stamina for Stop and Go** (page 17) surveys some of the R&D solutions that will restore power plant availability where it has faltered because of this changing pattern. Written by Ralph Whitaker, *Journal* feature editor, the article describes research with broad implications for countering many problems that have cut into fossil-fueled power plant performance and reliability.

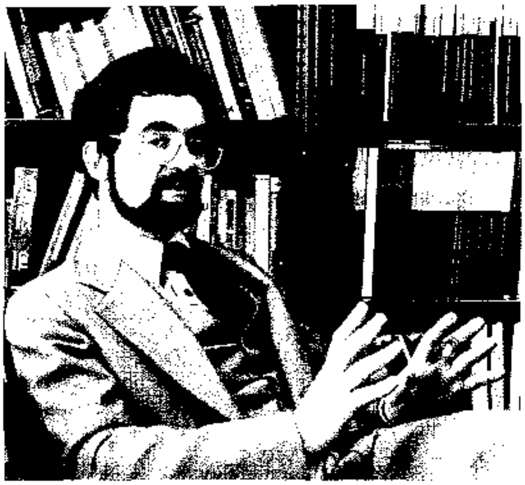
David Poole heads much of the relevant EPRI research, aided by John Parkes in those matters where root causes of failure are traceable to the turbine-generator. Poole came to EPRI's Coal Combustion Systems Division in June 1977 after more than 17 years with Detroit Edison Co., where he began as a plant operator, worked in the electrical systems and control departments, assumed engineering duties in the generation department, and then was responsible for special projects in the economics of reliability. On his final Detroit Edison assignment, Poole was in charge of all design and analytic phases of several improvement and maintenance projects at the utility's Monroe plant.

Since April 1977 John Parkes has been an EPRI project engineer in fossil plant performance and reliability. He was previously with Booz, Allen & Hamilton, Inc., developing energy project management systems. His major earlier experience was five years with General Electric Co., in development and design engineering of large steam turbine components. Parkes also completed a four-year engineering apprenticeship in Belfast, Northern Ireland, before attending Queens University there and earning a BS in mechanical engineering. He also holds an MS in mechanical engineering from Union College in Schenectady, New York.

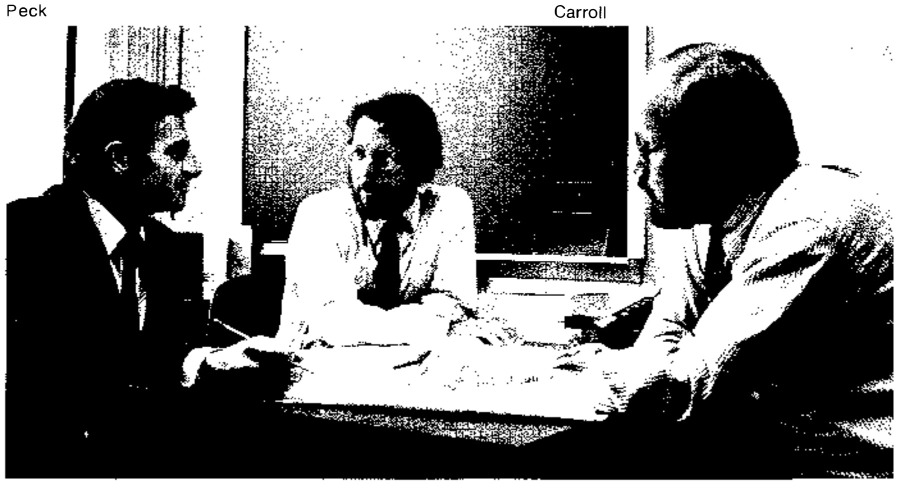
■

Fuels are becoming the world's swing commodity—an increasing influence on the evolving policies of most nations for their agricultural and industrial development, international trade balances, and internal security. **Energy Management Training for Developing Countries** (page 24) is thus an important commodity, and how the needs of different nations are met by various combinations of expertise forms the basis for this article by T. Owen Carroll.

Carroll is acting dean of the W. Averell Harriman College, State University of New York at Stony Brook, where he has taught for 12 years. He is also associate director of the university's Institute for Energy Research, which offers programs in energy management for government and industry officials from abroad. Carroll holds a PhD in applied physics from Cornell University and taught there before joining SUNYSB.


Peck


Carroll


Altouney Platt Browne


Poole Parkes

# NEW STRATEGY for an OLD GAME

Coal supply is a game of high stakes, elaborate strategies, complex rules, and uncertainty at every turn. The object is to get more coal from the ground to the power plants, but along the way, utilities and the nation must face challenges in coal exploration, mining, labor, transportation, and regulation.

The United States is sitting atop what may be part of the solution to the nation's energy problems—hundreds of billions of tons of coal. But coal in the ground is only the raw material for the solution: The nation must face the challenges associated with coal consumption and supply.

Coal has been demand-constrained for many years (and is expected to remain so for some time) by uncertain electricity demands, siting and financial problems, and environmental issues. As a result, most coal consumption forecasts prepared shortly after the Arab oil embargo of 1973 now appear unrealistically high. But even at lower demand levels, supply challenges must be met, challenges that stretch from the mine to the power plant.

By the year 2000, according to one EPRI estimate, the United States will require about three times the coal produced in 1978—or about two billion tons annually; if the nation supplies coal to other countries, that tonnage will rise further. To satisfy this demand, coal production will have to increase at an average rate of 4.7% a year. While this growth rate is not very large, production, constrained by demand, has grown by only 1.5% a year over the past 20 years. To meet this production goal, the nation must successfully meet challenges in coal exploration, mining, labor, and transportation. Thomas Browne, a project manager in EPRI's Supply Program, is optimistic about the coal supply challenge: "Exploration, mining, labor, and transportation have potential problems. But none of them appears to be unsolvable."

Supply challenges occur even before mines are opened. Information on the mineability and marketability of coal from a prospective mine is vital both to the mining company that will develop the mine and sell the coal and to the utility that will buy and burn the coal. Utilities, which use two-thirds of the nation's coal output, need information on a coal's Btu, sulfur, and ash content, as well as on other characteristics so that they can properly design new boilers or contract for the right type of coal to supply existing plants. Mining companies

need information on such mining conditions as seam depth, thickness, continuity, and the nature of mine roof and floor so that they can develop the mines in the most economical way. Without accurate advance information on a coal, a utility is not able to ensure that it can burn the coal with maximum efficiency. But without coal contracts for power plants under construction or for existing plants, mining companies are reluctant to risk opening new mines.

Although the United States has plenty of coal—some 430 billion tons in the demonstrated reserve base—there is some question as to how much of that coal is mineable and marketable. "Much of the coal that has been assumed to be recoverable may not be accessible for various reasons, economic and otherwise," comments Jeremy Platt, a geology specialist in EPRI's Supply Program. This uncertainty increases as researchers project supply further and further into the future.

The government estimates that approximately half of those reserves are recoverable at current prices, using today's technology; Browne maintains that "the assumption that half of the coal in the demonstrated reserve base could be mined at or near today's prices, using today's technology, has been shown to be overly optimistic by several researchers. However, there are probably large volumes of coal in less well defined resource categories that can be mined at a lower cost than coal shown in the demonstrated reserve base." Platt, who urges a better evaluation of coal mineability and marketability so that utilities can construct future plants and negotiate future contracts with confidence, adds, "We don't really know what we have, and I see little effort by either state or federal agencies to develop the necessary information."

EPRI now has several studies under way to provide a better grasp of coal information. One study (by the Texas Energy and Natural Resources Advisory Council, the Texas Bureau of Economic Geology, and the University of Texas) is uncovering important relationships in the geography of coal-forming swamps that help explain the continuity, thickness, and quality of coal seams. "The more we learn about coal, the more complex it turns out to be. This makes it increasingly hard to take for granted the resource numbers that are bandied about," remarks Platt.

Another EPRI study has attempted to evaluate the availability of coal resource information. This study (by ICF, Inc.) identified key information that mining companies and utilities need to know about a given coal, compiled a bibliography on existing coal resource information, and examined in depth two representative coal-producing areas to evaluate the quality and completeness of the available coal data on those specific places. The results of this study show the limitations of existing coal reserve and resource information.

#### Leasing and mining

Even though a mining company is confident of a market, there are still potential problems in developing a mine that may affect coal supply. One is access to the coal. Restrictions on mining rights come in a variety of forms. East of the Mississippi most land is privately owned, and the main issue is identifying the owners. But in the West, widespread coal reserves are held by the federal government and by Indian tribes, although surface rights may be separately owned. There the leasing of federal lands for mining takes an average of two or three years, but sometimes drags on for as long as six years.

The rate at which the government leases federal lands is a critical control on the pace of development. Throughout the 1970s federal coal was subject to a moratorium on leasing; during this period court cases were resolved and new leasing procedures were developed. The pace of leasing today depends on many complex issues currently being addressed by federal, state, and local governments, coal suppliers, public interest groups, and others.

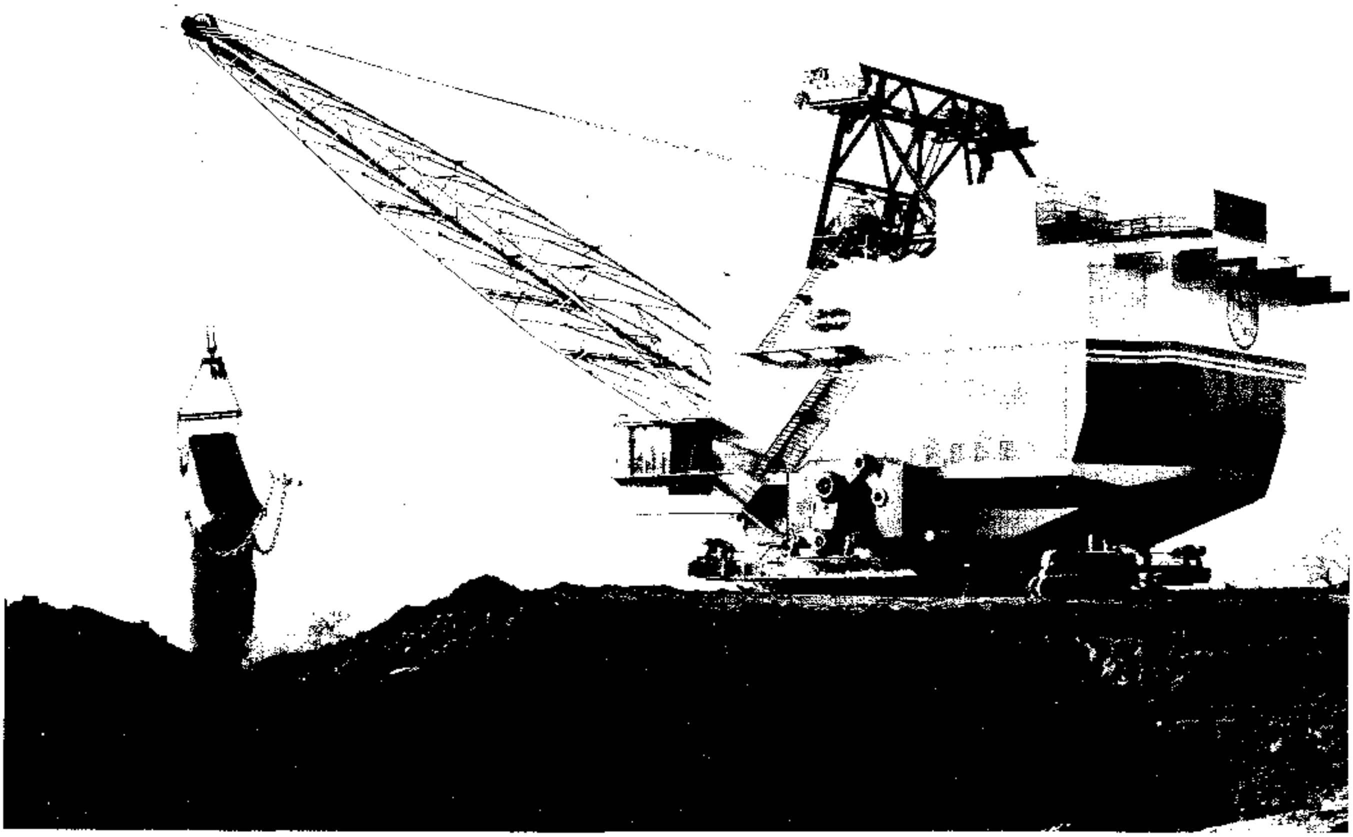
Browne emphasizes that coal lands will almost certainly be leased, but the long lead time between the initial move to secure leases and the granting of leases can have a discouraging effect on mine development. Milton Searl of EPRI's Energy Study Center adds that leasing restrictions may also mean a mining company will not get the best available coal or the most choice mining site. Other coal-bearing lands may not be leasable because they are prime farmland or are in areas deemed essential for groundwater migration. This, too, can have a negative effect on coal supply and price.

Another area that will affect mine development and, consequently, coal supply is labor. National energy projections have routinely assumed that labor factors will not significantly interfere with growth of U.S. coal production. While this may turn out to be true, there are many labor issues, some of which may create problems, others of which may represent opportunities to reduce costs, according to Browne. These include coal mining labor productivity, labor-management relations, and the socioeconomics associated with a growing labor force, particularly in the West.

For a better assessment of what the future labor situation might be, EPRI funded a study by The Conference Board that included projections of coal industry labor requirements, labor supply factors, and labor costs in 1990. The contractor also made a less-detailed analysis of the labor supply situation through 2030.

The recently completed study attributed productivity declines in underground mining to the combined impact of health and safety regulations, labor unrest, and post-1973 coal price increases that allowed the reentry or continuation of many higher-cost mining operations. In surface mining, lower productivity was caused primarily by tighter state reclamation laws and, again,



**By the year 2000,** according to one EPRI estimate, the United States will require approximately three times the coal produced in 1978—or about two billion ($2 \times 10^9$) tons annually To meet that production goal, important decisions must be made by those involved in coal exploration, mining, labor, transportation, and regulation.

by higher coal prices that permitted higher-cost mining operations. Given these productivity declines, a rapid expansion in the coal mining workforce might be necessary. Traditional labor pools should be able to accommodate such increases in the East. Nevertheless, there might be labor shortages in the western surface mines because of a smaller local labor pool.

The EPRI study, however, forecast that the mining industry's relatively high wages should allow it to compete successfully with other western industries for an increased share of the area's labor resources. These same high wages should also attract labor from other parts of the country. Expanded scope and quality of coal industry training programs might also prevent or mitigate such a labor squeeze; development of advanced mining technologies, such as automated remote-control systems for deep mining, might also help the situation.

The study also addressed average unit coal labor costs. Although these costs increased sharply during the 1970s (between 1972 and 1977 they rose at an estimated annual rate of over 7.5% because of the decline in overall mining productivity), the EPRI study uncovered a more positive trend. It projects that from 1977 to 1990, unit labor costs will increase at a modest average rate of about 1% a year above the rate of inflation.

In the area of coal industry labor relations, the EPRI study reported a substantial improvement in climate since the end of the 110-day 1977–1978 UMWA contract strike. According to Browne, both union and company officials have begun working to improve mine labor relations through better grievance procedures, labor relations training, and communications between management and union officials. "The quality of coal industry management is probably the most important factor in the coal industry's future labor situation," says Browne. "For coal supply to increase, management must successfully deal with a variety of labor-management and labor supply issues."

Another area that affects mining and hence coal supply is government regulation of mining activity. Besides the federal leasing already discussed, mining companies must contend with numerous other laws and regulations affecting all aspects of coal mining. Surface mining regulations, for example, require revegetation of mined areas, and underground mines must meet myriad health and safety regulations. U.S. coal companies are mining in accordance with present regulations, but the impact of future regulations on coal supply is difficult to predict. "We are uncertain about what issues may be addressed by future regulation, uncertain of future public and government response to issues, and uncertain of the cost of complying with future regulations," says Browne. These uncertainties can translate into coal supply delays.

### Transportation roadblocks

Perhaps the final consideration in expanded coal supply is the transportation of mined coal to utility and other customers. Railroads and waterways handle the bulk of U.S. coal traffic today, and as coal demand grows, these industries will have to grow along with it, according to Walter Esselman, director of EPRI's Strategic Planning Department. "There is a potential lack of adequate capacity in certain major coal-hauling areas," warns Edward Altouney, who manages the Supply Program's transportation projects. EPRI studies of present-day transportation systems have already pinpointed some of these problem areas.

"The western United States is a relatively new source of coal, and railroad shipping distances there are long," says Altouney. "Compared with the eastern United States, there are few rail routes. This means that most of the traffic goes over a few selected routes, and this can cause capacity problems."

There are also places where the rail network will require considerable upgrading. "In the East, many tracks have not received appropriate maintenance and are not adequate to haul unit coal trains, which average about 100 cars in length, each of which weighs some 100 tons when loaded with coal," Altouney comments.

Some of the capital improvements that will be needed are upgraded tracks capable of handling increased numbers of heavy coal trains and improved signal systems to facilitate smooth transport of the increased coal traffic, according to Esselman. But to ensure that improved transportation systems are available when coal demand goes up, advance commitment from utilities is necessary. "The problem," emphasizes Altouney, "is that while the railroads have seen increased coal traffic, that traffic has yet to increase to the levels shown in many forecasts. These forecasts have consistently overstated coal consumption, and the railroads are unwilling to invest until expansion is clearly demonstrated."

While railroads wait for the anticipated rise in coal traffic, bills aimed at deregulating the nation's railroads have been introduced in Congress. Such legislation might permit railroads to abandon underutilized lines. "This will improve their financial health," says Altouney, "and with improved financial health, perhaps main lines can be upgraded as necessary." On the other hand, utilities are concerned about the rates that may be charged for coal hauling under deregulation.

Another problem is the possible social effects of moving greatly increased volumes of coal across the country, suggests Altouney. Long, slow unit trains, lumbering from west to east, could crisscross states, disrupting towns along the way with traffic, dust, noise, and even derailments. This is not different from other freight traffic, but for a state that neither mines nor burns coal yet is regularly traversed by trains carrying the fuel, these negative aspects may be even more keenly felt.

There are solutions, but these may be

expensive. For example, the construction of underpasses or overpasses to lessen crosstown traffic congestion will be expensive and may require the demolition of existing buildings and roads. Tracks might be rerouted around towns, but at considerable cost.

Although railroads and waterways are expected to continue to transport the bulk of the nation's coal for a long time to come, there are several alternatives ahead. One such alternative is slurry pipelines that transport a mixture of crushed coal and water (or other fluid) to a final destination. Such pipelines may prove economical for transporting large volumes of coal over long distances. Most of the cost of a pipeline is construction-related, and once a pipeline is in place, costs are insulated from the rising prices of such commodities as labor and fuel. The least costly slurry medium is water; this is a potential liability if the coal in question is to be transported from the arid West. Altouney notes that there are several possible solutions, including the use of water drawn from deep wells, brackish water, or concentric pipelines that permit used water to be transported back to its place of origin.

Even if a pipeline is technically feasible, politics and economics are another question. Rights-of-way for these pipelines have proved to be difficult to secure, particularly where railroad rights-of-way must be crossed. Congress is now considering legislation that would grant eminent domain to slurry pipelines.

Long-distance transmission of electricity generated at minemouth power plants is a possible alternative to coal transportation. The ultrahigh voltage and dc technologies that make such transmission possible are now available, and extensive research is under way at EPRI to make these transmission systems more economical and more reliable for long distances. Of course, a conventional utility plant operating in arid western coalfields would still require

**Utility industry demand** for coal will be the mobilizing force behind the exploration of new reserves, the establishment of new mines, the recruiting and training of miners, and the expansion of transportation systems.

water, but EPRI is also investigating plant designs that use less water.

Given the uncertainties involved in coal transportation, EPRI now has a major study that will use a computerized model of the U.S. transportation network to examine in detail the transport of coal and other commodities. Traffic patterns are forecast for the years 1985, 1990, and 2000. Besides providing information on traffic flow and constraints on coal transportation, this C.A.C.I., Inc., study will look at the interaction between coal transportation costs and rates and the impact of localized increases in traffic relative to overall network flow. The physical changes necessary to smooth coal flow will be identified; future projects will examine the investments required to make these changes and their probable impact on transportation prices. Later projects will also evaluate the costs and benefits of coal slurry pipelines and the impact of potential legislation, including deregulation.

### Nation on the brink

The United States and the world at large remain poised for a return to coal. The resources to supply future demand are there, as the recent World Coal Study (Wocol) made clear. The study's conclusions: technically and economically recoverable reserves worldwide are large enough to support 1977 production rates for 250 years, and only 15% of these coal reserves would be used by 2000 even under Wocol projections of expanded coal use. New reserves are being discovered at a rapid rate. The technology for mining, moving, and using coal is established and steadily improving. The amount of capital needed to triple the production and use of coal and greatly expand world coal trade is well within the capacity of the world's capital markets. Many countries have adopted detailed legislative and regulatory systems for controlling the environmental, health, and safety effects accompanying increased coal use. For the most part, the technology is available to comply with the most stringent of the current environmental standards in each country at costs that leave coal competitive with oil at mid-1979 prices.

"This is an optimistic message, but it is not a self-fulfilling prophesy," comments Wocol's organizer, Carroll L. Wilson of MIT. "The lead time between signing a contract for the output of a prospective new mine and using its coal hundreds or thousands of miles away in a new power plant can be as much as 10 years. The potential bottlenecks in between are numerous. The price of delay at any one of these points can be disastrous: too little coal, too late."

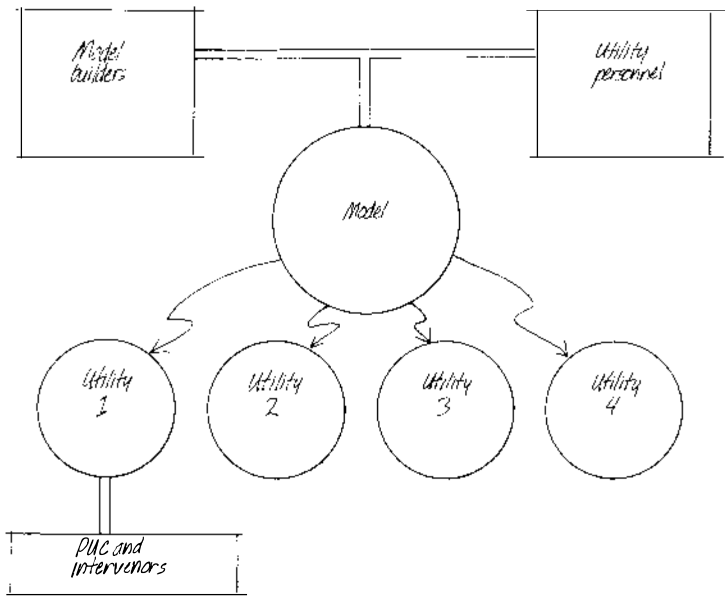
Utility industry demand for coal will be the mobilizing force behind the exploration of new reserves, the establishment of new mines, the recruiting and training of miners, and the expansion of transportation systems. But within the industry, utilities are hesitant to move forward with new coal-burning plants, notes René Malès, director of the Energy Analysis and Environment Division. Unexpected downturns in electricity demand have made future demand forecasts uncertain. Even if future demands were certain, utilities would find it difficult to build because of tough air quality controls on new plants, water supply problems, and licensing and financing hardships. Whatever the reasons, "Only a few coal plants are being built," says Malès. "The coal industry has to be assured that coal will be needed. The utility industry has to be assured that coal can be delivered. Unless both industries are sufficiently confident," concludes Malès, "the coal transportation systems and mines won't be there when they are needed."


**Further reading**

*The Labor Outlook for the Bituminous Coal Mining Industry.* Final report for RP1147-1, prepared by The Conference Board, August 1980. EPRI EA-1477.

*Coal Resource Information*, Vol. 3. Final report for RP868-1, prepared by ICF, Inc., March 1980. EPRI EA-673, Vol. 3.

*Coal Supply Alternatives for Rural Electric G&T Cooperatives.* Final report for RP868-2, prepared by ICF, Inc., January 1980. EPRI EA-1270.




Several computer models have been built to help utility planners with major decisions in the present uncertain environment. From an early stage in the construction of a model, EPRI and its contractors work directly with utility advisory groups. When complete, the model may be sent to a wide range of utilities so they can gain a deeper understanding of their own decision problems and communicate those insights to utility commissions, intervenor groups, and others.

# Models: A Resource for the Decision Maker

Keeping consumers' electricity bills as low as possible is the main aim of utility planners. But there are many uncertainties and myriad decisions to be made on the way. In fact, the very number and complexity of factors to be included in utility planning tend to clog the decision-making process, especially when utility plans must be approved by public utility commissions and other regulatory bodies, as well as accepted by the general public and special interest groups. Consequently, construction of new generating plants is frequently postponed, and switchover to more-economic plants is often delayed—holdups that can eventually mean an increase in consumers' electricity bills.

To speed up the decision-making process, computer models are being built that focus on utility planning options and assist utility staffs and regulators. René Malès, director of the Energy Analysis and Environment (EAE) Division at EPRI, explains a crucial point: "In simple systems, the human mind can probably hold 6–10 variables and massage them rather thoroughly. But when one faces multiple sets of very uncertain factors, the human mind can't do the total integration. That's what the model does. It doesn't make the decision; it shows the possible consequences of making the decision. And it may sometimes highlight details the decision maker had not thought were very important."

When the electric utility industry first established EPRI, the primary concern was research that had to be done in terms of new and improved technology and hardware. But after EPRI started operations, its R&D managers realized that the choice of technologies to be funded by EPRI was substantially affected by economic and environmental uncertainties. It became clear that economics and environmental science could offer valuable insights for many major decisions. The EAE Division was established to provide a fact base for EPRI's R&D planning. Later, it was realized that the methodologies used in that division could provide insight for many decisions made by electric utility companies.

So far, EAE researchers and their contractors have developed three models that can help utility planners decide which routes to take to achieve reasonably priced power service for consumers. One model tackles questions on the size, or megawatt capacity, of a generating system to obtain an optimal margin of reserve power. A second model focuses on the system features that should be adopted to influence the ratio of peak to baseload power. A third model examines problems in selecting the type of plant to build, that is, how the costs and benefits of one kind of plant should be weighed against those of another.

The basis of all three models is decision analysis, a method that segments a problem into three parts: the options open to the utility manager, the im-

The three models described in this article are based on decision analysis, which separates the decision process into three parts: what alternative decisions are to be made; what the important uncertainties affecting the outcomes of the decisions are, and how the outcomes should be valued.

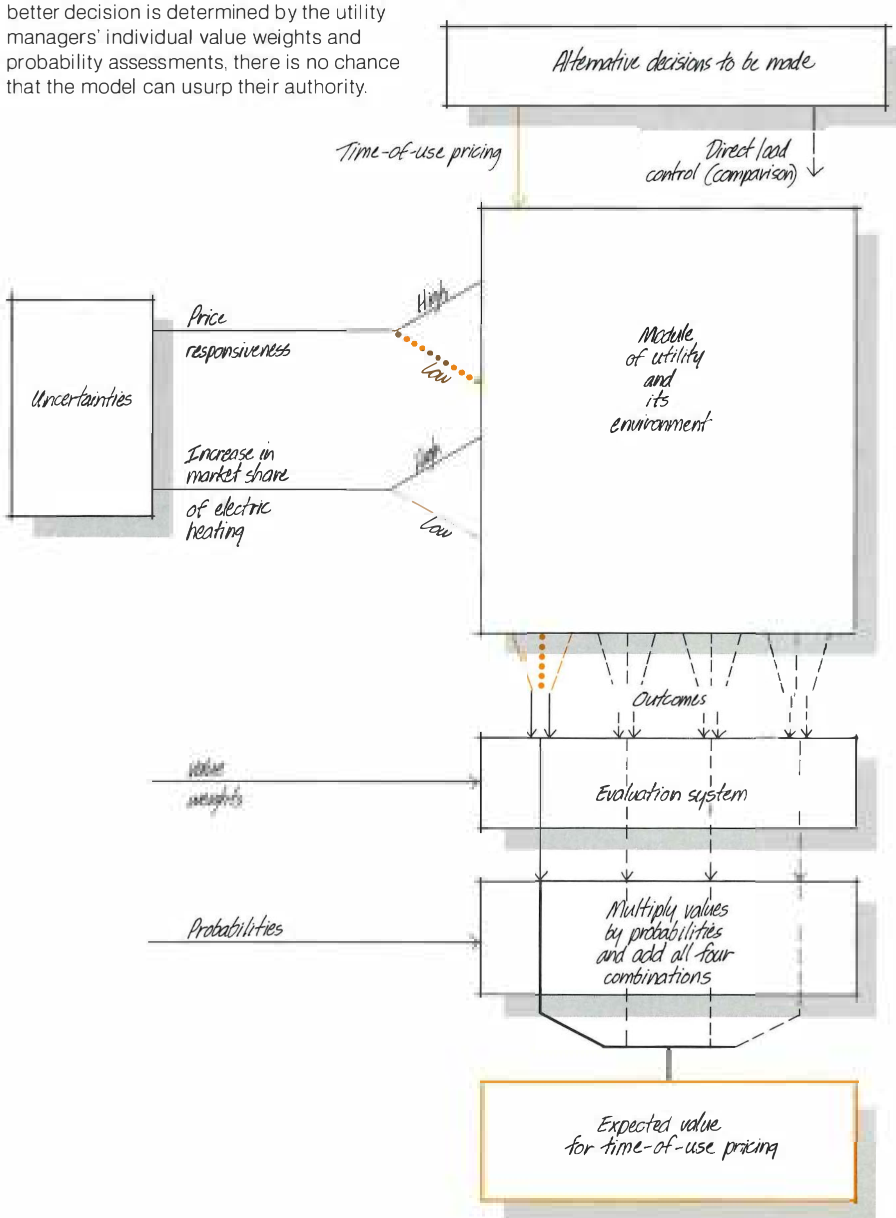
For example, in making a decision on load management, there could be two alternative ways to manage the load, plus two important uncertainties and two important outcome elements. (In a real case, there would be many more variables.) The utility in question might wish to decide between time-of-use pricing for residential customers and utility-operated, direct load control of residential air conditioning. (Only the process for time-of-use pricing under one set of uncertainties is illustrated.)

The first of the two uncertainties might be the degree to which residential customers would shift their electric demand from peak to off-peak periods in response to time-of-use pricing. This price responsiveness may be high or low. The second uncertainty might be the increase in market share of electric heating, which also may be high or low. Utility managers would base the probabilities on their judgment.

Two outcome elements might be the utility's revenue requirement (the cost its customers pay) and the stability of net revenue from year to year. Utility managers would choose weights representing the relative importance of the revenue requirement and the revenue stability outcome.

For the decision on time-of-use pricing, this example produces four possible combinations of high or low price responsiveness and high or low increase in market share of electric heating. For each combination, a weighted sum of the revenue requirement and the revenue stability is formed. This value is multiplied by its probability, and the four combinations are added together to produce the expected value for time-of-use pricing.

The same set of steps is followed for direct load control, producing another expected value, which is compared with the value for time-of-use pricing. The higher expected value constitutes the "better" decision. Because the better decision is determined by the utility managers' individual value weights and probability assessments, there is no chance that the model can usurp their authority.



portant uncertainties affecting the outcome of each decision, and the evaluation of outcomes by the utility manager and the utility's customers. The decision maker's information in these areas forms the complex inputs to the models.

For maximum efficacy, models are best built when utility analysts are members of the working team. At an early stage, utility participants advise modelers of their major concerns and discuss a desirable model structure.

At a later stage, models are tested by EPRI researchers and their consultants, who take several utility systems as case studies and work closely with three or four staff members from the utility concerned.

Copies of one EPRI model, called the over/under capacity planning model, have already been requested by about 100 utilities, regulatory commissions, government research organizations, and consulting firms. Still at the testing stage are the other two: the load management strategy testing model and the technology choice model.

All three models are tools in decision making, not substitutes for the decision maker. The purpose of the models is to give the decision maker insights into the complex questions that arise rather than reams of numbers that need to be interpreted and interrelated.

#### Size of the system

Traditionally, utility plans for expanding capacity were made against a background in which the load forecast was believed to be reasonably firm. The only way a utility could fail to generate sufficient power was if a large number of generating units were unexpectedly out of commission. Many utilities planned their capacity expansion so that the probability of failing to meet the load (loss-of-load probability) was low.

In the 1960s the economic future was fairly certain, and forecasting load was generally a matter of extrapolating from the historical growth rate of electricity use. Energy modeling at that time was the domain of the engineer. Today capacity expansion models that view the future as certain may no longer be fully appropriate.

A new model developed by EPRI and Decision Focus, Inc., explicitly introduces the uncertainty associated with load growth and examines the common utility dilemma of deciding whether to risk the extra capital costs that accompany a high ratio of capacity minus expected demand to capacity (the reserve margin) or to risk the probable costs to consumers of shortfalls in power service that may result from a low reserve margin. When the over/under capacity model was applied to four utilities in different parts of the United States, it was discovered that addition of the high costs of electricity outages to the costs contained in consumers' utility bills made it less expensive for consumers if the utility supported somewhat higher reserve margins.

The simple lesson of the over/under model is that because electricity shortages are very costly (from 50¢ to $1 per unserved kWh) relative to incremental generation (about 3¢ per kWh), it is better to take the risk of having too much capacity than too little. Other EPRI findings indicate that the range of costs of unserved kWh (outage) is wide—from 90¢ to $3.98, but probably average between $2 and $3 per kWh.

Before the model was developed, this concept had not been expressed convincingly in a utility planning model. Now that it can be shown as a total-cost curve (with fixed, variable, environmental, and outage costs on one graph), it is clear that both very low and very high margins of reserve capacity are a financial burden on the consumer. Very low reserve margins, characterized by a high incidence of unserved energy, hurt the consumer most. The curve also shows that a certain percentage range of reserve is optimal—a range often higher than past estimates because of uncertainty and the need to replace uneconomic oil-fired units.

Utility planners can now plug into the over/under model estimates of the fixed costs of building additional capacity and the variable fuel and operating costs, as well as the charge rates for the environmental impact of various generating technologies and an outage charge rate representing the cost to consumers of unserved electrical needs. One way to decide on an appropriate outage charge rate is to base it on data collected in extensive interviewing of the utility's customers to find out the costs they incurred for substitute power, inconvenience, discomfort, even danger.

About 40% or more of electric generating capacity in the United States has been analyzed by using the over/under model. Results of applying the over/under model have been presented as evidence at regulatory hearings on levels of generating capacity. For instance, plans by a large midwestern utility to construct a nuclear plant were challenged by intervenors who contended that smaller, coal-fired units would require a lower reserve margin. By means of the over/under model, however, the utility planners were able to demonstrate that although the alternative plan would indeed result in lower reserve margins, the costs to consumers would increase by $100 million annually.

To provide better input for the model, more data are being gathered about the assumed monetary effects of outages, their frequency and duration. In a recent study, EPRI found that consumer costs during chronic power shortages in Key West, Florida, were higher than previously estimated and ranged from 90¢/kWh to $3.98/kWh, with certain consumers, such as hospitals and supermarkets, predictably valuing reliable electricity service more highly than other types of consumers.

Two extensions of the over/under model have been built, one in greater breadth, the other in greater depth. The first, which was recently completed at the Center for Energy Studies, University of Texas at Austin, computes a range of optimal reserve margins on a regional basis and compares them with industry expansion plans. The National Electric Reliability Council is cooperating in this project. The second, developed by Decision Focus, Inc., examines the way technology mix (the proportion of one type of plant to another in a utility) affects the costs of service to consumers.

### Load management

For most utilities, the pattern of their customers' electricity use is not distributed uniformly through the day and year but is concentrated in peak periods. To meet the peak load needs of their customers, utilities have to construct generating units that are used only part of the time. Often, utilities will build lower-capital-cost units to meet these needs but at a trade-off of lower efficiency and a more expensive fuel. Thus, if less electricity is used in peak periods in the future, there would be potential savings from the increased use of existing units and reduced use of expensive fuels. But the question is how can such a reduction in future peak demand by customers be accomplished?

*Load management* is a term for policies aimed at modifying load curves with the purpose of reducing costs. Such policies can include time-of-day pricing, direct load control (by utilities) of specific customer appliances, and energy conservation. While these programs may reduce the costs of supplying electricity by changing the pattern and level of electric power loads, they impose additional costs that must be compared with the savings. These costs include not only the extra meters and control equipment but also the possible customer inconvenience and the reduction in the quality of the service.

Four factors make load management decisions difficult. First, there are numerous options and combinations of options to consider. Second, the interaction of customers, utilities, and regulators makes the potential impact of load management hard to estimate. Third, there are many goals ascribable to load management; thus a particular program may be successful at saving oil but unsuccessful at reducing costs to customers. Fourth, uncertainties are great about the degree of customer response to load management and the availability of new load management technologies.

The model being developed by EPRI and Decision Focus, Inc., will help utilities make decisions about load management despite these difficulties. While the model is in the testing stage, EPRI is working with the industry to ensure its usefulness. For instance, a discussion workshop was attended by staffs from 10 utilities and 2 regulatory commissions; case studies are under way with three utilities to field-test the model; and model demonstration workshops will be held to explain and test the model further.

### Technology choice

EPRI, Woodward-Clyde Consultants, and staff from a western utility company have developed a model for technology choice whereby utility decision makers can look at the possible consequences of their decisions and assign values to complex outcomes.

Traditionally, the choice of the plant type a utility might decide to construct was based on standard economic ways of looking at costs. Nowadays, however, when a utility commits itself to construct a new generating unit, it must consider a number of potential risks related to siting, licensing, and water requirements.

EPRI's technology-choice model is built around those issues. It provides an analytic framework to help utility planners evaluate technology choices, not based solely on economic factors but on a comprehensive analysis that combines all the major impacts, such as economic, licensing, siting, environmental. It can help utility decision makers hypothesize if, for example, it is in a utility's interest to commit to a technology with apparently lower long-term capital and operating costs but a high likelihood of rejection by siting commissions and the general public, or if it should select a technology with higher projected costs but a greater chance of acceptance. In other words, how much risk should a utility take in an effort to achieve lower long-term costs?

The model will not give an answer to such questions, but it will highlight the risks of any one decision route. In fact, because the model has to incorporate the decision maker's own weights for the relative importance of the outcomes and probability assessments of the uncertainties, there is no danger that the decision maker will lose authority in the decision process. The model will exist as a tool of the human mind, not as its replacement.

A series of workshops will be held early in 1981 for utility modelers who are interested in learning how to operate the technology-choice model.

### Framework for debate

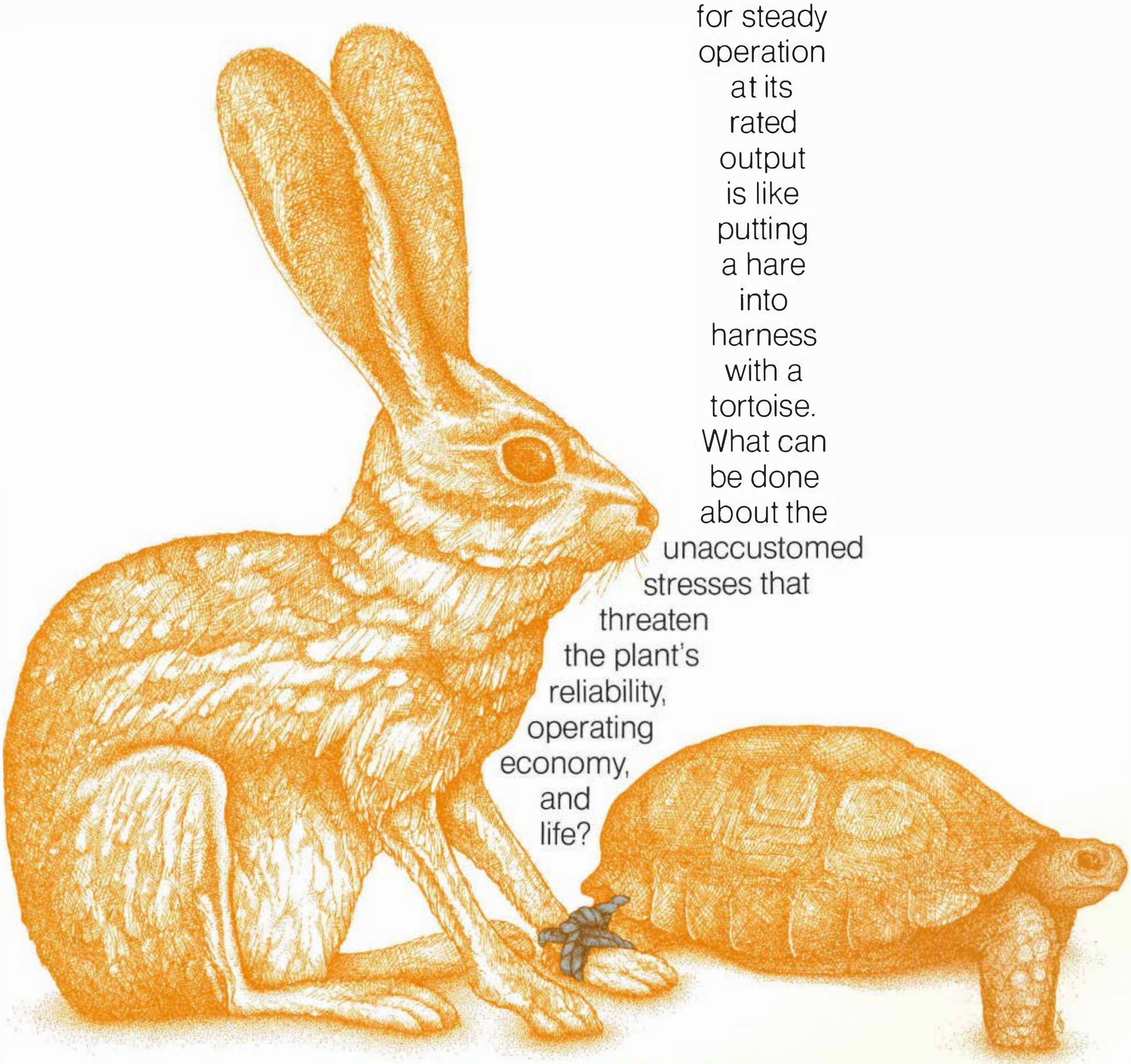
In a planning environment characterized by major uncertainties, the new planning models can reflect the importance of those uncertainties in the process of seeking minimum costs for consumers.

In building a model, EPRI and its contractors work directly with a utility to include all relevant considerations. When the model has been transferred to the utility, the contractors provide a follow-up support service to answer questions that arise from day to day.

The new models can serve as frameworks for debate; for instance, the over/under model can help by facilitating resolution of technical issues before they reach public hearings. Consumer groups and others could run the model to make calculations based on their own data and compare the results with utility data and results. In this way, all issues that can be agreed upon are cleared up before the hearing.

Thus, the new models reduce recurring arguments and allow irrelevancies to be discarded early so that major objectives and issues of planning stand ready for scrutiny.

Cycling a power plant that was designed for steady operation at its rated output is like putting a hare into harness with a tortoise. What can be done about the unaccustomed stresses that threaten the plant's reliability, operating economy, and life?



# STAMINA FOR STOP AND GO

Long before energy conservation became a nationally acknowledged goal and the highway speed limit was cut to 55 mph, automobile drivers were counseled, "You don't have to start up like a jackrabbit. It's hard on the engine, cuts tire life, and wastes gas."

These points about good driving have direct analogies for utility power plant designers and operators. Paralleling our experience with cars, fuel economy suffers at anything other than design conditions. But reduced efficiency isn't all. That's just the wasted fuel. There is also the heightened wear and tear, the more frequent repair and replacement of parts, and ultimately, a shorter life for the entire machine.

The stop-and-go problem arises for utilities when their power demand patterns change but their generating equipment cannot. If a power plant still has economic life to be realized, scrapping it prematurely penalizes the utility and its ratepayers. Today's inflated cost of building a new plant that is designed to meet changed operating conditions would, in effect, be a further penalty.

**Startups and shutdowns**

Among utilities the problem is that coal-fired generating plants designed for steady baseload operation are instead being cycled up and down to match the swings in daily electricity demand. There are at least two reasons why this is happening. First, nuclear power plants begun as long as 10–12 years ago are now coming on-line. Also designed for baseload, they have lower fuel costs; moreover, regulatory mandate requires their essentially steady-state operation. Second, overall electricity demand growth is slowing, so the baseload is not rising fast enough for many coal-fired plants to continue operation at their designed ratings. Thus, they are being relegated to on-off cycling or downgraded to reduced-load operation.

David Poole, manager of EPRI's R&D program in fossil plant performance and reliability, acknowledges that this trend was even more pronounced before Three Mile Island than it is today. As it is, regulatory delay of new nuclear generating capacity is holding a lot of coal-fired plants in baseload service longer than was previously expected. But the cycling problem is only put off, not solved. At best, according to Poole, the postponement is giving R&D managers at EPRI and in utilities some welcome breathing room: a horizon of perhaps five years instead of two years against which to improve coal-fired plant reliability and control under cycling conditions.

Evidence of the problems that result from cycling shows up in the records of plant availability (the percentage of time a plant either is or could be generating power). If a plant is forced to be idle, with no possibility of generating revenue, its ownership cost is an unplanned drain on the utility's operations. Industrywide availability of large coal-fired units (400 MW and larger) has fallen significantly in the past 15 years—from about 80% to just below 65%. But baseload plants that have been pressed into cycling service seem to have suffered disproportionately.

**Reduced-load operation**

The problems that result from cycling are twofold: those that stem directly from internal temperature changes as they occur during cycling and those that stem from relatively steady operation at any load significantly less than was contemplated in the plant's original design. Not only are former baseload plants being cycled off and on in daily two-shift operation, but they are often needed for only a fraction of their rated output.

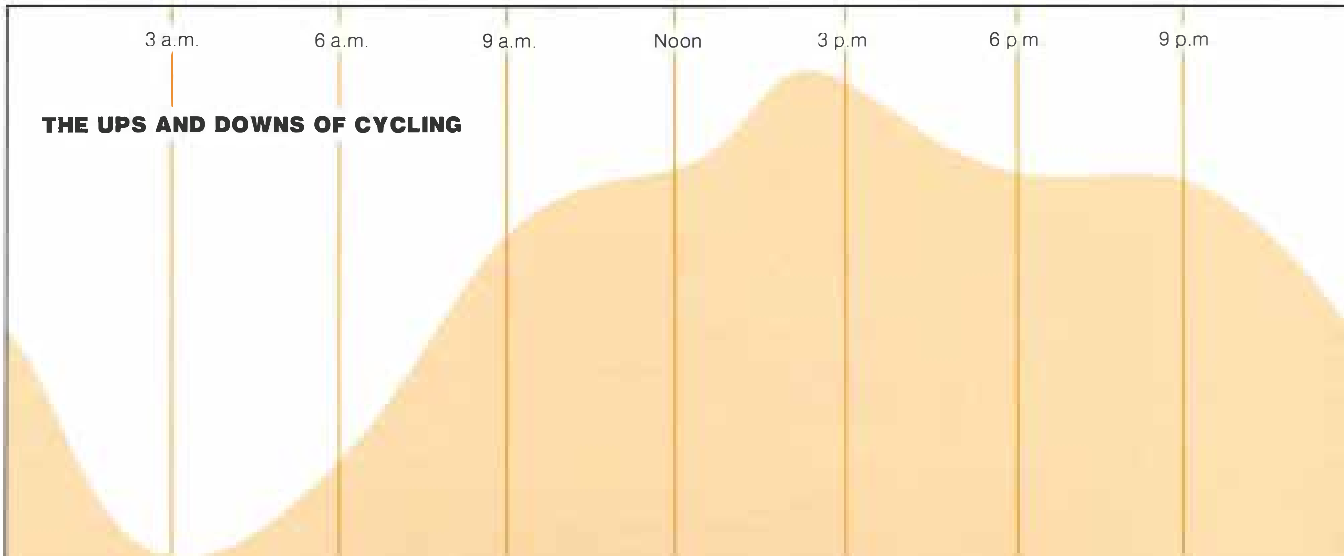
The automotive analogy continues to be useful as we recall the plaintive or even outraged response by owners of high-performance cars when the 55-mph speed limit was imposed: "But my Porsche was designed to go fast! I'll use even more gas at 55 than I do at 65 or 70. I'll foul the plugs, I won't get efficient cooling, and the whole engine will suffer."

Indeed, some of the largest and most recently built coal-fired generating plants are the least tolerant of off-design operation. Designed to run at supercritical steam temperature and pressure, and fitted with the latest and most complex environmental cleanup equipment, these plants cannot readily be controlled by their automatic systems at loads less than ~50% of rated capacity. They become unstable and require frequent manual intervention to adjust and balance temperatures, pressures, and flows throughout their fuel, air, water, and steam systems.

In contrast, many older machines are stable down to 30–35% of rated load. This stability encourages utilities to choose their older plants, which also have the lowest ownership costs, for service at reduced load. Even at some sacrifice of efficiency and fuel economy, the overall economic motivation is clear and logical. But the technical consequences are not so clear. Despite plant controllability, internal conditions come into play as an adverse influence if the plant was originally designed for baseload service. Thus, whether a prime mover is compactly shrouded beneath the sleek hood of a sports car or is functionally framed by structural steel alongside the stacks and cooling towers of a utility power plant, it is designed to meet specific criteria. If those criteria are followed, the machine will work well and last long. When conditions are changed, something suffers.

**Solutions across the board**

EPRI's problem-solving task is easily seen in the context of cycling and the associate condition of reduced-load operation. But the downward trend of availability also stems from circumstances that affect all coal-fired plants; for example, irregular and generally declining coal quality that upsets smooth firing, fouls boiler and heat exchange surfaces, and overloads the equipment designed to clean exhaust gases. The research under Poole's direction therefore applies to nearly all fossil-fueled utility power units in the United States. (A unit is an individual boiler-and-turbine combination, of which there may be as many as 8 or 10 in a single plant.) There are more than 1050 such units; 278 of them are rated 400 MW or more, and at least 130 of these are rated 600 MW or more. Altogether, they account for nearly 70% of




## THE UPS AND DOWNS OF CYCLING

When utility engineers and operators speak of cycling, they refer to a range of variations in power plant output to meet a number of operating requirements. At one extreme are the minute-to-minute fluctuations in electrical load experienced by a generating unit even while it is running steadily at a nominally full load. These fluctuations are mostly accommodated by automatic controls, and the scope and precision of those controls are important for finely tuned, fuel-efficient electricity generation. At the other extreme is the relatively infrequent total shutdown of a unit for maintenance and repair, whether unexpected (forced) or scheduled, and its subsequent startup.

But in between and of major concern to EPRI and other researchers among utilities and manufacturers are the overnight or weekend reductions in output, either to as little as 40% of rated capacity or to a complete standstill. This is the regimen of intermediate power generation: not as steady as baseload but far more so than peaking generation, for which specially designed plants operate only a few hours daily, such as on hot summer afternoons or cold winter mornings and evenings, when residential, commercial, and industrial power requirements coincide. In terms of an entire year (8760 hours), a baseload plant typically runs for more than 4000 hours and a peaking plant, less than 1000. The serious problems arise in the intermediate range of 1000–4000 hours of annual operation.

If any phenomenon of cycling could be called an umbrella for these problems, it is temperature change. Its frequency and extent dictate its effects. Whereas a baseload plant may be brought down only 10–12 times annually, an intermediate plant may be brought down frequently—thus possibly more than 150 times. Some of these cycles may be only a retreat to a reduced load, but in many cases they involve a complete turndown to zero load. If this is only overnight, say, from 11 p.m. to 6 a.m., then steam conditions are maintained, the machine cools only moderately (say, from 1000°F to 900°F), and a hot start follows. If it is for a weekend, from Friday night to Monday morning, then firing ceases, system temperature falls lower (to 700°F), and a warm start follows. A shutdown of six days or more, for any reason, allows the entire machine to stabilize at ambient temperatures, and a cold start is required.

Each of these cycles calls for a different operating sequence with different rates of temperature change, both as the unit is brought down and as it is later brought up to go on-line again. Cycling is thus costly, because there is economic value in the time required to get on-line. Spinning a turbine without generating saleable electricity is unproductive.

Most of all, there is the cost of aggravated wear and tear on the plant as materials and parts heat up and expand or cool down and contract at different rates, creating transient conditions in clearances, friction, chemical reactions, and internal stresses. The temperature changes originate in the combustion gases and are reflected in water and steam conditions. But even with the best control of the rate of change, they influence chemical behaviors between and within the fluid and solid materials. And they affect the mechanical properties of components, structures, and machinery throughout the plant, taking a toll of strength and longevity. □

U.S. utility generating capacity today.

Furthermore, more than 300 fossil-fueled units of all sizes are now in various stages of planning and design. More than 90% of these will be coal-fired. Experience dictates they must be designed for a flexibility that will permit reliable and economic operation in a cycling mode early in their productive lives.

A good deal of EPRI's research applies equally to nuclear power plants, although there are more rigorous categorical design differences for fossil plants. Turbines in fossil plants generally run faster (3600 versus 1800 rpm), hotter (540°C versus 290°C; 1000°F versus 550°F), and at higher steam pressures (16.5–24 MPa versus 6.9 MPa; 2400–3500 psi versus 1000 psi). Fossil plant rotating components tend to be smaller, with higher unit stresses and lower stress margins.

Reliability research only begins with individual component failures that result in outage and lost availability. EPRI's dissection and analysis of availability records have done much to correlate cyclic plant operating patterns with these failures. Examples include worn and corroded turbine blades, cracked turbine rotors, leaky boiler tubes, fouled heat exchange surfaces, failed auxiliary machinery, and even occasional catastrophes like furnace implosions or explosions, lost turbine blades, or burst rotors.

Getting at the root causes of these failures is something else. The examples reviewed here are drawn from EPRI research that has established one or more root causes for a number of lost-availability problems and in several cases has produced equipment specification guidelines or operating guidelines to eliminate them.

#### Particles in steam

Temperature changes in power plant machinery begin at the boiler as hot combustion gases turn water into steam. Subsequent temperature changes follow the path of the steam. Simplistic but convenient logic therefore suggests beginning with the high-pressure turbine, which first absorbs energy as steam is admitted during startup.

Turbine-generator availability losses are the special province of EPRI's John Parkes. His research results now show that blades in the first rows, or stages, of cycled turbines frequently suffer from erosion that can only be caused by particles carried in the steam. This erosion becomes apparent as a loss in efficiency, and it is confirmed by observation during maintenance outages that require the turbine to be laid open. Both blades and nozzles are affected.

Depending on design details that differ from one plant to another, Parkes notes, erosive wear may be more pronounced in the first stages of the intermediate-pressure turbine. This is a clue to its cause, because both high-pressure and intermediate-pressure turbines are turned by steam that has come directly from superheaters or reheaters.

The root cause of hard-particle erosion is rapid oxidation of tube surfaces in the superheaters and reheaters and also (more recently learned) in the main steam piping. Such oxidation is a function of tube material and temperature, and even at steady-state conditions it results in the formation of scale. But contraction and expansion of the tube and pipe surfaces with cycling makes the difference, causing hard particles of scale to spall, or exfoliate. Especially during startup, when steam flow is increasing, scale particles produce wear in the turbine nozzles and first stages of blading. Exfoliation and erosion may continue thereafter, but at a reduced rate.

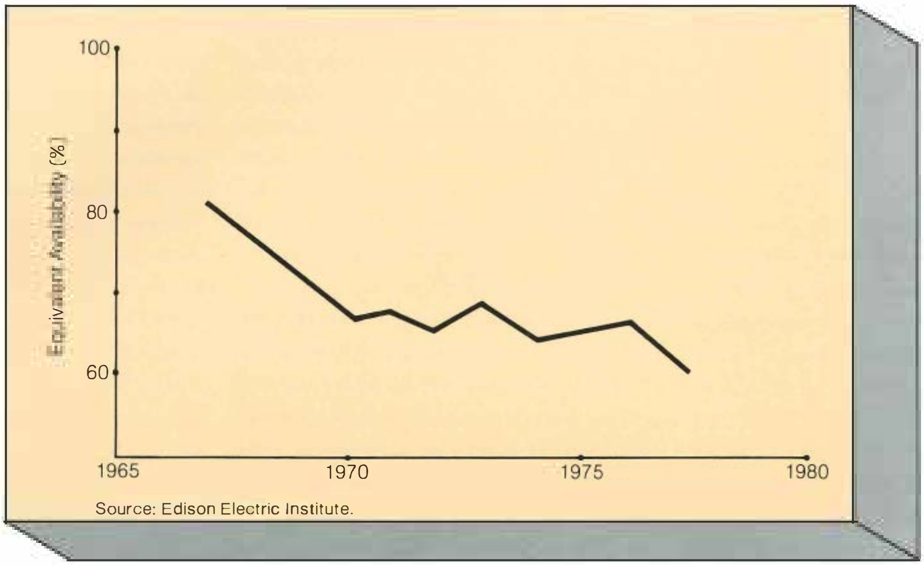
Among the clues to the role of tube temperature change in hard-particle erosion is its less frequent occurrence in European equipment, which is usually designed for daily cycling. To shorten shutdown and startup times without subjecting the boiler and turbine to mismatched temperatures, steam bypasses and variable-pressure operation are employed. During startup the steam is split, some passing directly to the condenser and some being used to operate the turbine. The more evenly maintained temperatures seem to reduce exfoliation and the consequent hard-particle erosion of turbine blades during startups.

Turbine bypasses may well become a part of future U.S. designs for a number of reasons, cycling flexibility among them. But closer at hand is a promising retrofit measure for plants that were not originally designed to cycle. This measure is chromate conversion treatment of boiler tubes and steam lines to inhibit rapid oxidation. The technique has been successfully demonstrated in the laboratory, using elevated temperatures for accelerated tests of performance life under cycling conditions.

A second research avenue to deal with hard-particle erosion involves wear-resistant coatings for turbine blades. Coating uniformity and adherence are vital, because a flaw or crack in the coating could permit highly localized wear or induce a blade crack that might go undetected until the blade has been weakened enough to break.

#### Corrodants in steam

Feedwater chemistry and equipment are subjects in themselves, with no clear-cut resolution as yet for relieving the ill effects of cycling or reduced-load operation. Kenneth Lehner, project manager, is assessing the methods used to reduce water and steam impurities and to scavenge free oxygen from boiler feedwater. He observes that some demineralizing materials may occasionally contribute impurities to the feedwater. But demineralizing is a necessity for the makeup water introduced to offset boiler leakage and losses through shaft seals. Impurities also enter through condensers, where vacuum conditions cause inleakage. Sodium and various sulfates and chlorides are corrodants that especially attack the final stages of low-pressure turbine blading. Sodium, for example, is specified by turbine manufacturers to be




Averaged data for all coal-fired utility generating units of 400 MW and larger show a severe downward trend in equivalent availability, a measure that reflects reduced-load operation as well as forced and scheduled outages. The scheduled outages account for about a 13% loss of availability.

**AVAILABILITY LOST—FORCED OUTAGE (%)**

| | | |
|---|---|---|
| **Boilers** | | **8.0** |
| Tubes | 4.2 | |
| Slagging and fouling | 2.7 | |
| Controls and cycling | 1.1 | |
| **Turbine-generators** | | **9.5** |
| Generators | 3.8 | |
| Turbine blades and disks | 2.7 | |
| Bearings and lubricating systems | 2.0 | |
| Controls and cycling | 1.0 | |
| **Auxiliaries** | | **8.0** |
| Condensers | 3.8 | |
| Boiler feed pumps | 1.7 | |
| Fans | 1.3 | |
| Pulverizers | 0.6 | |
| Valves, feedwater heaters, other | 0.6 | |
| Total | | 25.5 |

Source: EPRI estimates based on Edison Electric Institute data.

controlled at a level of 3–5 ppb, but the concentration is temperature- and pressure-dependent; it can increase when conditions are upset by cycling.

Low-pressure turbine blades are affected by a combination of phenomena known as stress corrosion and corrosion fatigue. These result from the deposition of corrodants, which is especially severe in the last few rows of blades, where steam begins to condense. Corrosive effects in this region are heightened by the stresses there, including stress from a shock wave created where the steam velocity (momentarily supersonic) drops to a subsonic level. Blade pitting is the first manifestation; it generally induces cracking, which is further propagated by corrosion fatigue until reduction of the blade section and strength causes its premature failure.

Changes in steam conditions upstream can make the shock wave unstable, as well as move axially along the final stages of the low-pressure turbine, thus producing high-frequency alternating stresses on blades. Cycling also causes the point of steam condensation (the Wilson point) to move; deposited salts are alternately moistened and dried, increasing their corrosive effect. The principal foci are the blades, their attachments, and (in large turbines) the interfaces of the rotor and its separate but shrunk-on disks that carry the blades. These are points of high inherent mechanical stress.

Besides improved feedwater chemistry to reduce the incidence of corrodants, means are being sought to detect them so as to schedule periodic blade washing or replacement without the cost and disruption of a forced outage. Neutron activation instrumentation is under development to measure corrodant concentrations in operating turbines. Other techniques are being borrowed from the technologies of nondestructive evaluation: the detection of acoustic emissions from stressed components or detection of changed vibration patterns (signatures) in turbines.

A more direct solution is likely to be the specification of titanium as the material for blades both stronger and more corrosion-resistant than steel. Titanium is also more expensive, but not in proportion to the costs that result from an extended forced outage. EPRI research is expected to produce and test prototype titanium blades late next year; specification guidelines should make them commercially available within another year.

### Creep fatigue in rotors

High- and intermediate-pressure turbine rotors operate in the creep regime; that is, creep stresses are imposed on them by the combined mechanical and thermal conditions of steady load. However, cold and warm starts impose additional cyclic creep stresses. Rotor design and operating criteria therefore take into account some expected number of cycles in a normal 40-year life. The number is much greater in a turbine designed for cycling. When a baseload unit is cycled, its rotor life may be substantially reduced.

Temperature gradients between the outside surface of a rotor and its bore can contribute to this process. The metal section is very thick, so changes in steam flow are carefully controlled to avoid excessive temperature gradients. A replacement rotor is so expensive that cracking from creep fatigue must be avoided.

The record contains few instances of burst rotors—true catastrophes that throw a deadly centrifugal shower of steel through the turbine casing. But routine inspections often reveal the precursor condition of cracked rotor bore and outer surfaces. These occurrences are traceable to cycling, but their rate of incidence among different rotors does not correlate consistently with the number or rigor of cycles experienced.

Rotor design and operating criteria are therefore under investigation. The theoretical models of temperature gradient from rotor periphery to bore may not reflect reality; both steady-load and cycling stresses may be greater or less than those now used to design various rotor dimensions. Operating criteria for the time needed to safely heat or cool a rotor during startup or shutdown may therefore be incorrect.

To ascertain the true values of bore temperatures and the patterns of their change in cycling, EPRI has sponsored a three-year project of temperature measurement in a Commonwealth Edison Co. unit. This work is an instance where assessment of the problem was a challenge in itself: a special assembly of thermocouples had to be developed, together with the means to telemeter their data from the bore of a spinning turbine. Extensive temperature records have now been amassed, and the associate stresses are being determined, to be compared with theoretical models that will be revised as necessary to produce new operating criteria. From the comparison of old assumptions with new findings, it should be possible to make extrapolations applicable to other rotors and to develop faster startup and shutdown sequences, while maximizing rotor life.

Basic improvements in rotors are also being sought through projects of an EPRI program in materials research, headed by Robert Jaffee. Rotor metallurgy and forging practice are being probed and altered under contracts with Japanese and German manufacturers. Impurities and their effects in the microstructure of cast ingots and subsequently forged rotors are being identified and eliminated. Identical rotors produced by two processes will be installed, operated under normal conditions, and monitored by Southwestern Public Service Co. and Southwestern Electric Power Co. Installation is planned for 1981.

A further approach to the problem of rotor cracking is bottle boring—periodically reaming and smoothing bore surfaces during scheduled inspections to eliminate early cracks and the points of stress concentration they represent.

### Boilers: fire side and steam side

Heat transfer is fast in the water walls of a utility boiler and in the steam superheater and reheater tubes laced in and out through the convection region. Materials sections are thin to permit the efficient exchange of heat between combustion gases and water or steam.

There are several dissimilar metals and thousands of welded tube connections in a boiler. Temperature change, whether it results from cycling or from suddenly upset firing conditions, quickly finds the weak points in those metals and welds. Repeated thermal excursions cause tube leaks at welds. Overly high temperatures cause hydrogen embrittlement and tube failure. Chemical reactions at both steam- and fire-side surfaces lead to corrosion failures.

Faulty welds are a high-priority problem. There is now no acceptable way to distinguish good dissimilar welds from bad ones. X rays, the classical tool in other fields, are not adequate to the task. EPRI research seeks a reliable nondestructive evaluation technique for this application; but if necessary, future research will be directed toward new tube materials and new welding methods.

Water chemistry, here as elsewhere, is a subject of research in reducing steam- and water-side corrosion. And corrosion-resistant coatings, either permanent or sacrificial (designed to be gradually destroyed by hot combustion gases and erosive ash), are a further option on the fire side. If developed, such fire-side coatings might have the property of inhibiting slag adherence. This possibility addresses related boiler problems created when combustion temperature excursions cause normally solid ash particles to melt and then condense on water walls and tubes. Molten slag is highly corrosive. Moreover, when it solidifies in place, it inhibits heat transfer, causing derating or total shutdown of the unit.

Variable coal quality has a role in slagging and fouling, but unstable boiler control after cycling down to reduced load is also important. Coal pulverizers and air fans (either forced draft or induced draft) do not then run smoothly. Pulverizers tend to transmit coal in uneven slugs. Fans lug and vibrate and create pulsations in air flow. These circumstances upset the fuel-air mixture and disturb the kinetics of combustion as well. Temperature excursions are reflected in further cycling effects that require moment-by-moment operator adjustments of valves and pumps throughout the water and steam systems downstream.

One possible retrofit solution is the resort to more pulverizers, each having smaller throughput capacity at full load. Reduced load would be served by running fewer of these pulverizers.

Fan problems need a different approach. Furnace draft must be uniform, but it is difficult to control at low flow rates. At worst, unbalanced draft can cause a furnace to explode if the forced-draft pressure becomes excessive or to implode if the induced-draft suction becomes excessive. Short of these disastrous effects, uneven pulsations in the moving air can be damped by creating controlled turbulence. This is the effect produced by an EPRI-sponsored device called a jet flap fluidic control damper. Now being developed with the aid of plant operating data from two utilities, Consolidated Edison Co. of New York, Inc., and Florida Power Corp., the new damper exacts a small penalty in efficiency but contributes to controlled stability at reduced loads.

### Cycling control and its value

Throughout the foregoing review, emphasis has been given to the control of process phenomena produced by cycling large coal-fired power units. But there is also the problem of controlling the plant machinery itself through cycles of startup and shutdown and at off-design loads. The rate of cycling is one thing; the control precision to attain it is another; the stability of equipment at a given load is a third.

All these are ideally achieved by automated systems that incorporate computer programs for varied starting and loading sequences (as well as the reverse sequences) and for the many circumstances that arise from perturbation or failure of nearly any component in the unit. A collateral objective of EPRI's research in fossil plant performance and reliability is to optimize those sequences and to refine the capabilities of electronic, hydraulic, pneumatic, and mechanical components that make them happen.

The projects in Poole's program alone carry a price tag expected to be about $10 million in 1981 and totaling some $70 million for five years, 1981–1985. The research goal is to provide the technology for improving average equivalent availability by five percentage points in those same five years. Poole is optimistic about his progress, pointing, for example, to a published guideline for specifying boiler feed pumps that will avoid the problems encountered at off-peak flows.

Poole is also aware that his availability improvements, even if uniformly implemented, could net out to zero under the impact of the separate, continuing problems of poor coal quality and poor reliability of environmental control equipment. But even this prospect does not detract from the value of Poole's program results. They are foreseeably worth as much as $125 million annually for just one percentage point availability improvement throughout the utility industry's coal-fired units of 600 MW and larger. This figure falls out of calculations using a conservative 12 mills/kWh as the fuel displacement value, that is, the fuel cost differential incurred by a substitute generating unit when coal costs $36–$40 a ton. It also reflects a capacity value of $0.50 a kW week.

For EPRI's targeted improvement of five percentage points in availability, the near-term potential value among some 130 large coal-fired units exceeds half a billion dollars annually. And this does not include the longer-term value of R&D-based technology improvements that will add cycling flexibility to newly designed units. The stop-and-go pattern of cycling service is with us now. The stamina to deal with it will take only a little longer. ■

# Energy Management Training for Developing Countries

If the rural poor are forbidden to use wood as a fuel because of deforestation risk, what alternatives do they have? Urgent questions on basic living needs, as well as national viability, besiege planners in less-developed countries.

by T. Owen Carroll

How do planners project the energy needed for transportation in Mexico City? How are issues of fuel pricing for coal and electricity resolved in Indonesia? What are the implications of mining large quantities of high-quality, low-sulfur coal in Colombia?

Such real-life questions are debated as case studies by participants from less-developed countries (LDCs) who attend energy management training courses. Three of the available courses are in France, Argentina, and the United States. At Stony Brook, New York, the course is divided into week-long minicourses on specific topics related to the development of fossil and renewable resources, and it includes seminars on investment analyses for capacity expansion, national pricing issues, industrial conservation, and fuel alternatives for the rural poor.

National energy planning has become a critical element in guiding a country toward economic and social development. Many countries have already responded to the changing energy situation by forming national committees on energy. For example, Kenya has formed the National Committee on Energy Policy and Resources, Thailand has the National Energy Administration, and Ecuador has created the Institute for Energy Analysis. In these cases, the intention is to move toward integrated energy policy planning that reflects the interplay of labor, technical expertise, capital, and other considerations in energy expansion for development. But where are the energy planners who will be expected to provide leadership? Those who are most likely to occupy future positions as energy planners in the LDCs are now government ministers and utility officials, energy researchers and engineers in the private sector, and university staff and graduate students. Energy management training can provide the prospective energy planners with an opportunity to view economic development in their countries in terms of energy needs and to translate those needs into specific requirements for fuels, technologies, capital, and expertise.

### Energy planning issues

Both the real and the perceived energy problems of LDCs differ widely throughout the Third World. There is no doubt that the crisis in all the oil-importing LDCs arises from such factors as the severe deficits in the balance of payments caused by the precipitous rise in oil prices, the growing shortage of noncommercial fuels, and the lack of capital for investment in indigenous energy resources. Yet in identifying the context for energy planning training in LDCs, one should distinguish between three generic types of countries: lower-income, predominantly exporting LDCs like Tanzania, Malaysia, and the Dominican Republic; small, industrialized countries like Korea, the Republic of China (Taiwan), and Thailand; and large, more-industrialized developing countries like Brazil, India, and the People's Republic of China.

This article is adapted from a paper delivered by T. Owen Carroll at the Workshop on Energy and the Developing Nations, cosponsored by EPRI and Stanford University, Palo Alto, California, in March 1980.

The energy situation in the Dominican Republic is more or less typical of that to be found in many of the first group—the smaller, primarily exporting LDCs. The Dominican Republic relies almost exclusively on imported oil to meet its commercial energy needs and on sugar and nickel for its export earnings. Recent price increases in oil have outpaced those in either nickel or sugar. At the same time, steady growth in population and increased migration to the capital city, Santo Domingo, have brought about a sharp upturn in consumption of commercial fuels. Given the urgency for higher national economic output, energy use per capita is also increasing as the government struggles to step up the industrial contribution to the gross national product. As in many of the lower-income countries, the so-called noncommercial fuels, which, of course, are no longer actually noncommercial, are disappearing; in fact, in the Dominican Republic deforestation is so extensive that it is against the law to cut down a tree. As a consequence of this scarcity, more and more small industries and families in urban areas are turning to commercial fuels, such as electricity. This further aggravates oil demand because most of the electricity in the Dominican Republic is generated by oil-fired plants.

In the long term, the Dominican Republic, like many of the small, primarily exporting LDCs, faces a transition from oil to indigenous fuels. This transition will require a tremendous investment of capital and human resources. It will also require major changes in the mandate of organizations that up to now have dealt with the delivery of energy. The sheer size of this undertaking will reduce the capital resources available for investment in other sectors of the economy. As a result, plans for the economic and social development in these countries, which aim at diversifying their export products to lessen sensitivity to commodity price shifts and at establishing light industries capable of reducing the need to import consumer products, may have to be delayed or, at best, altered to reduce their energy intensiveness.

In the near term, there will be a strong need to allocate oil and other scarce fuels, as well as the capital invested in energy infrastructure, in a more economically efficient manner. This means more government involvement in pricing both commercial and noncommercial fuels, in controlling the import of energy-using devices, and in setting mandatory controls on energy use in energy-intensive industries and transportation.

While the second group of LDCs—the small, industrialized countries—must address many of the energy planning issues noted above, the rapid industrialization and urbanization over the past decade have already introduced the structural energy-economy links that will make it difficult for them to abruptly reduce their relatively high per capita commercial energy consumption without invoking serious economic dislocations, a fact that most of these governments realize. On the other hand, many of these countries may be able to price their exports to reflect increases in oil imports and more quickly put into place new conventional and unconventional energy supplies.

Korea, for example, has installed a

large number of nuclear reactors and, at the same time, has replaced oil use in industry with indigenous coal. It is also rapidly restricting the use of oil by consumers and is mandating energy-use efficiency in medium and heavy industry. Energy planning issues for countries like Korea center on such questions as how changes in the energy price structure will affect the economy, how the country can maintain the export market for its manufactured goods and continue pricing products to reflect the increase in the cost of imported fuels, and how the government should plan for the long-term global situation of a diminished supply of oil and, perhaps, of uranium.

Because the economies in these countries are more diversified and their energy supply-demand systems include a wider mixture of fuels, they have a wider range of options available. At the same time, their wider access to capital markets and more extensive supply of skilled manpower allow them to consider a more multifaceted approach to their energy problems.

For the third group of LDCs—larger, newly industrialized countries like India, Brazil, and soon the People's Republic of China—the primary issue is to find the means to develop indigenous resources so as to continue the headlong rush toward a modern economy. The rapid increase in oil import costs in India and Brazil has been met by aggressive programs to find short-term solutions for maintaining growth. India and the People's Republic of China are stepping up the use of coal, and Brazil is producing large quantities of sugar-based alcohol fuel. For the long term, energy supply continues as the focus of national energy planning. All these countries are investing heavily in the exploration and exploitation of oil and natural gas resources. Near-term energy plans focus on industrial energy conservation and, to a lesser extent, on developing a better basis for a rational energy pricing policy.

All the large LDCs have huge rural populations who face shortages of energy because of the declining supply of traditional fuels. This will be true even for the People's Republic of China if its population continues to grow and migration to urban areas remains restricted. The problems surrounding the provision of new energy resources to rural peoples are substantially different from those in the urban and industrial sectors. In a sense, they are also more difficult, for much less is known about the intervening technologies that will have to be used. Nevertheless, the planning and management of rural energy delivery systems are bound to become a major preoccupation in these countries over the next decade.

### Training needs

LDCs, particularly the oil-importing countries, have a pressing need for energy technologists who are trained to find, assess, and exploit conventional fossil resources. This is particularly true for the many countries who expect to locate usable quantities of oil in amounts insufficient for export. This makes it difficult for them to attract foreign companies as partners in resource exploitation on terms that both governments are likely to find acceptable. Coal technologists will be much in demand because geologists predict that coal of low and medium quality will be found in many areas of the LDCs, and there are relatively few experts in this field of technology.

To expand the supply of fossil fuel technologists, it is first necessary to establish appropriate funding at a number of university and technical institutes in the LDCs and then at the numerous institutions in the advanced and industrial countries. No such funding exists for expanding the supply of technologists who can assess and establish unconventional resources and also technologies for better energy end-use efficiency, in spite of the fact that both these concepts are the only options available to LDCs that have to reduce dependence on oil imports. Moreover, in the case of many unconventional resources, the training needed does not blend easily with programs in the conventional engineering schools and technical institutes to be found in most LDCs.

Although it is not the intent to give a detailed description of the requirements for training large numbers of energy technologists, it is appropriate to comment that neither international nor national assistance agencies have undertaken any large programs to support the expansion of training efforts in the LDCs. Nor have there been significant efforts to support institutions in the advanced industrial countries that seem willing and able to undertake this kind of training on a large scale. There are a few exceptions, however. The United Nations is sponsoring a series of short seminars on renewable resource use. The U.S. Agency for International Development (USAID) is supporting a special program at the University of Florida, which will offer an intensive 15-week course on renewable resource technologies for participants from LDCs. A number of other small efforts are under way at DOE and USAID. Also, USAID, the United Nations, and several European assistance agencies are considering the funding of much larger efforts.

One may argue that the most serious impediment to mobilizing large-scale technology efforts in the LDCs to reduce oil dependence may not be the lack of energy technologists but rather the shortage of capital. If this is true, the demand for energy technologists in the LDCs may not begin to accelerate until the middle or the end of this decade. But at that time, the demand is likely to far exceed the capacities of educational institutions in the LDCs and in the advanced industrial countries, unless major efforts are made within the next few years to develop training centers at top-rated institutions in LDCs. Institutions in the advanced countries can and should be involved in these training centers, but only in a supporting role.

Unfortunately, the above rationale for expecting that a few years may go by before the demand for energy technology training accelerates does not apply to energy management training. Diminishing energy supplies and expanding demand, in fact, suggest the need for prompt action by the governments of the LDCs to bring energy demand into balance with available supplies without producing severe dislocation to their economy and social structure.

It is clear there is already an urgent need for large numbers of energy management experts in the LDCs, but it is not so clear how to train these people, who must quickly be made familiar with appropriate background material, methodologies, and techniques, and who must have the specialized experience that this training calls for.

There is much to be done in a short time. In thinking about mechanisms that would allow energy management training to be carried out on a worldwide basis, it seems important to maximize the use of LDC institutions for at least two reasons. No other practical way exists for training large numbers of people, particularly at the lower levels. Perhaps more important, when it comes to the teaching of energy management for LDCs, it is difficult to separate the political from the analytic dimensions, even if one thought it best to do so. At the same time, one must recognize that there are only a handful of institutions in the LDCs where engineers, economists, and others come together to work actively in this field.

To estimate numbers of people likely to be trained over the next decade, Stony Brook staff has extrapolated from field studies in about 30 countries, using data collected in rural and urban energy system analysis, national energy assessments in selected LDCs, and special seminars and training.

For a small, primarily exporting country like the Dominican Republic, probably 5–10 senior officials from various ministries would participate in short executive seminars. The seminars would best be organized at the regional level (South America, Caribbean, Central America, Southeast Asia, Middle East, West Africa, and East Africa), where joint and common interests in energy-economic policy and planning are best emphasized. The number of professional staff needed in the future to support energy audits, field surveys in the rural energy system, and monitoring of price impacts would be large. In the Dominican Republic, for example, the estimate for those needing training over the decade is 160–170. At present costs, which are about $5000 per participant, the training cost would be about $800,000 for the decade, or about $80,000 a year. Oil import costs in the Dominican Republic are now $150 million a year. Thus, if as a result of attendance at energy planning and management courses, the individuals are instrumental in reducing oil consumption by, say, less than 1%, they will have compensated for their training expenses. The point is that the cost of developing a well-trained staff for energy investment planning is well within the budget capability of even the smaller LDCs, while at the same time the benefits of better energy management, measured by any reasonable standard, will be enormous.

### TRAINING CENTERS

Information on energy management training can be obtained from the following.

Institute for Energy Research,
State University of New York at Stony Brook.
Stony Brook, New York 11794;
(516) 246-8230.
Robert Nathans, director; James Bever, codirector.

Commissariat à l'Energie Atomique.
P.B. 510, (1) 75752 Paris Cedex 15, France; 273-6000.
Achille Ferrari, asst. chief of programs.

Fundación Bariloche, Departamento de Recursos Naturales y Energía.
C.C. 138, 8400 San Carlos de Bariloche, Prov. de Río Negro, Cangallo 1719-1A, Argentina; 0944-25755.
Dr. Carlos Enrique Suárez. □

In the small industrialized countries, there have been more extensive planning efforts. Thailand, for example, has a national energy administration staff of about 150, many of whom can be expected to participate in some kind of midcareer energy management training during the decade. Other staff working in energy fields in other ministries raise this number to 400. An approximate training cost over the decade is $2.5 million, or $250,000 a year. A similar situation exists in Korea. Compared with the cost of oil imports, the training costs in both countries are small. Korea and Thailand have reflected this high payoff in recent years by sending many individuals to training centers and graduate programs.

The energy training needs in Brazil, India, and, in a few years, the People's Republic of China are apt to be similar to those of the smaller industrialized countries. Brazil already sends many government and energy research personnel to the United States and European institutions for advanced training in the energy field. Professional training is beginning to evolve at some of the university centers. With oil imports at $12 billion, there are strong incentives to establish government capability to perform the broad range of energy management, planning, and monitoring tasks. Moreover, this planning capability is being complemented by a growing specialization in energy resource technologies, such as oil shale, coal, and alcohol.

It is difficult to extrapolate the total non-OPEC LDC demand for energy-related training over the next decade, but a crude estimate puts the total at perhaps 100 executive seminars, 2000 persons entering energy management training programs, and perhaps 10,000 persons entering professional staff training. From this estimate, it is obvious that the industrialized countries cannot be the only source of training. Rather, the development of LDC training centers must be viewed as the basis for long-term energy planning and management programs. ■

# UTILITY ASSOCIATIONS: Services Tailored to Different Memberships

Three associations of the utility industry fulfill their members' needs by offering many special services. Augmenting EPRI's programs, they conduct R&D of particular relevance to their member systems.

Washington, D.C., is more than the home of the federal government. The nation's capital also houses the headquarters of 1400 trade and professional associations, more than any other city in the country. Located within a half-mile of each other in Washington are three trade associations of particular significance to EPRI: the Edison Electric Institute (EEI), the association of investor-owned electric utilities; American Public Power Association (APPA), the association of public and municipally owned utilities; and the National Rural Electric Cooperative Association (NRECA), the association of rural cooperative utilities. The three associations address the needs and concerns of their members through workshops; seminars; management training courses; annual meetings; weekly, monthly, and annual publications; and a variety of information services and programs. Their Washington location enables the associations to represent the views of their members to Congress, the federal agencies, and the administration.

EPRI and the trade associations share members. Currently EPRI's membership consists of 134 of the 249 investor-owned utilities, 261 of the 1050 rural cooperatives, and 240 of the 2223 municipals, plus the federal systems of the Tennessee Valley Authority and the Bonneville Power Administration. Except for cities served by TVA and BPA, each trade association oversees the collection of funds from its members for EPRI's support.

Like EPRI, the three associations are aware of the ever-increasing importance of R&D. EPRI's focus on research may be more comprehensive than that of the other three organizations, but EEI, APPA, and NRECA conduct and manage projects of significance to their own member utilities. "We are interested in those technologies that are adaptable to smaller utilities for the generation of power and for distribution," explains Alex Radin, APPA's executive director. NRECA's members have special research concerns because of their wide geographic distribution. EEI's research activities are directed toward analytic results rather than specific hardware research projects. "The research that we do is economic and statistical and also has to do with the functions of the people within the utility company, such as personnel research," according to Jack Young, EEI's senior vice president for Conservation, Communications, Customer and Industrial Relations.

## Analytic Research

Founded in 1933 and incorporated in 1970, EEI merged with the National Association of Electric Companies in 1978 and moved its headquarters from New York City to Washington in 1979. William McCollam, Jr., president of EEI, directs a staff of 250 organized into seven groups. Discussing the significance of R&D, McCollam feels "there is a general awareness throughout the electric utility industry of the importance of research and the evidence is the strong support that EPRI is now getting."

EEI's R&D efforts resulted in the Electric Research Council (ERC), formed in 1965. When EPRI was founded in 1972, it assumed the research activities of ERC and the management responsibilities for the R&D programs of EEI. Looking to EPRI to conduct research on future energy technologies, EEI now concentrates on statistical and analytic studies on electricity supply and demand. "We perform analytic studies that are analogous to some types of studies conducted at EPRI. It is important for us to coordinate our research so there isn't duplication, and then we can carry on work that is complementary," remarks Justin Karp, vice president for engineering and systems operations.

The Engineering and Systems Operations Division, which is part of the Energy and Environmental Activities Group headed by Senior Vice President John J. Kearney, carries on these complementary operations by maintaining extensive contact between EEI's technical committees and EPRI. For example, the chairmen of the 12 committees under the Engineering and Systems Operations Division each designate one committee member as liaison to EPRI to keep the Institute informed on projects of concern to that committee. "A primary purpose of the committee structure is the exchange of information among the companies in our industry," explains Karp. There are currently 3000 member company officials involved in the many committees that carry out the policies and programs of the seven groups of EEI.

The staff of the Economic and Regulatory Policy Analysis Group, directed by Senior Vice President Douglas C. Bauer, produces many of the analytic studies that EEI performs for the investor-owned utilities. The Oversight Committee for Economic Growth in the Future, for example, has prepared an analysis of economic and energy trends over the next 40 years. *Economic Growth in the Future II* (EGIF-II) is an update of an earlier EEI study, which examined three basic scenarios of future energy and economic growth in the U.S. The revised study uses new modeling techniques to examine five scenarios. The revision was coordinated with EPRI, which provided modeling and forecasting resources. All the analytic work on the project was performed by the EEI staff under the direction of Jerry Karaganis, director of energy modeling.

The *Annual Electric Power Survey* and *Statistical Year Book* are two annual reports also produced by the Economic and Regulatory Policy Analysis Group. The *Survey* presents historical data on peak load, capability to meet load, and kilowatthour requirements for the nine regions of the National Electric Reliability Council, as well as forecasts of likely trends in those areas over the next 10 years. To obtain the data, the staff works in cooperation with representatives of electric power systems or power areas throughout the 48 conterminous states and with manufacturers of heavy electric power equipment. The information in the *Survey* covers the U.S. electric utility industry, including investor-owned, federal, state, municipal, and rural cooperative systems.

EEI's *Statistical Year Book* also taps the total electric utility industry as a source for statistics on generating capacity, electric power supply, energy sales, customers at year-end, revenues, and operating data and ratios. In addition, combined financial statements are presented for the investor-owned sector of the industry.

Besides these large, comprehensive documents, EEI also publishes weekly and monthly statistical reports for its members. The Energy and Environmental Activities Group prepares and disseminates guides on such specialized subjects as boiler fuel and flue gas additives, turbine blade problems, cable operations, land-use planning, and spent nuclear fuel. The publications of the Conservation, Communications, Customer and Industrial Relations Group (including *EEI News Highlights* and a quarterly journal, *Electric Perspectives*) keep member companies up to date on activities and developments within EEI and on the views of the industry. These reports, studies, and publications are but one aspect of the many services offered by EEI to its member utilities.

## System-Specific Research

Many of the rural cooperatives are distribution systems that buy power rather than generate it themselves. Many of the municipal systems also buy power at wholesale rates from investor-owned utilities, federal power agencies, and other public power systems. These systems have, therefore, a large investment in the reliability of electricity transmission and distribution. But reliable distribution is only one area of research that is particularly significant to these other systems. Relying on EPRI to focus on research applicable to all types of utilities, the municipals and rural cooperatives have a need for system-specific projects to meet their concerns. Their trade associations, APPA and NRECA, retain 20% of their members' contributions to EPRI in a special research fund for projects unique to their members' needs.

Since it was created in 1940, APPA has helped its members deal with the problems of providing service on a local level. APPA's commitment to research is shown through the projects that are selected by its Committee on Electrical Research. The committee currently has approved 20 projects that APPA is helping to fund. Radin finds that "as we are confronted with conditions we never had to face before, research is more important than ever. I think we are in a different era now, one where we have to make some rather fundamental changes in course, and research is absolutely essential to the future of the electric industry." Radin currently directs a staff of 42 that provides a variety of services for the APPA membership of 1400 municipal systems.

Since 1974 APPA has awarded almost $1 million for many types of research projects. Ongoing projects are managed by a steering committee that serves in an advisory capacity to the host utility, university, or company where the research is being conducted. The steering committee is composed of utility engineers and managers from other member utilities who make certain that the scope, schedule, and direction of the projects are followed.

One project, focusing on distribution cables, is in the second phase of funding from APPA. Cable Technologies Laboratories, New Jersey, is developing a procedure for in-service treatment of extruded 15–35-kV cables to extend the cable service life. The utility industry could save millions of dollars each year by increasing the operating life of underground distribution cables.

This year APPA has awarded research grants for three projects that will focus on cogeneration. Nashville Electric Service is designing an energy recovery facility that will produce electric power and process steam from municipal solid waste for several private industries and state institutions. The plant will burn an average of 1500 tons of municipal waste a day.

McCollam

Partridge

Radin

The Springfield (Illinois) Water, Light, and Power Dept. will study the feasibility of building and operating an atmospheric fluidized-bed power plant with a closed-cycle gas turbine at a local coal plant. The fluidized-bed system has the capacity for high efficiency, low cost, simple design, minimum environmental problems, and cogeneration.

A bulk power supplier, Massachusetts Municipal Wholesale Electric Co., has designed a demonstration project of space heating that uses power plant reject heat. The company's new headquarters will serve as the demonstration site, using reject heat from a 346-MW intermediate combined-cycle power plant adjacent to the office building.

Two of the most recent projects initiated by APPA involve using waste heat to produce fresh water from salt water in Key West, Florida, and the retrofit of diesel engines to burn alcohol in Vandalia, Missouri.

Diesel technology is particularly important to the municipal utilities. "There are about 2000 diesel engines used by the members of APPA," notes Eric Leber, APPA's director of energy research. "But these engines are being used less and less. In fact, the Iowa Association of Municipal Utilities recently surveyed its members and found that the engines were only operating about 2% of the time because they couldn't find or couldn't afford fuel." APPA conducted a workshop on diesel technology to identify the fuel and hardware options available to keep diesel engines operating. A proposed project at Iowa State University in cooperation with APPA will research the use of corncobs as a source of gaseous fuel for diesel engines.

Another energy technology that is of interest to the small utilities is the fuel cell because it appears to be a technology that is not married to economies of scale. "Fuel cells may become the diesel engines of the future," comments Herb Blinder, APPA's director of technical services. "The utility industry is becoming far more interconnected, regardless of plant size. In terms of a regional electric power supply, our members' diesel plants are diversified, small plants close to individual load centers. Fuel cells look like a very fine application for replacing that type of generation." Further, Leber believes EPRI has been quite flexible and responsive in accommodating the interests of the smaller utilities, particularly in programs like the Fuel Cell Users Group, "which largely grew out of initiatives within EPRI."

The energy research section of APPA is starting a new program, the Demonstration of Energy Efficient Developments (DEED). "This effort is being developed with a near-term focus of trying to get some of these new technologies out into the field," comments Leber. Part of the DEED project will be to publish a quarterly newsletter, the *DEED Digest*, where all APPA's research results will be summarized. The results of APPA's research efforts are also publicized in the bimonthly magazine of APPA, *Public Power*, and in its newsletter, *Public Power Weekly*.

When NRECA was organized in 1942 there was a serious problem facing the rural electric cooperative utility systems. As a result of the early war effort, the U.S. Office of Production Management prevented the use of materials required for rural electric lines. With the assistance of NRECA the problem was solved by convincing Congress that electrified farms would be a boon to the war effort. But problems still persist today in bringing electricity to rural areas of the nation. The rural cooperatives, for example, own and operate over 40% of the nation's miles of distribution lines but serve only about 10% of the U.S. population.

Some of these problems can be solved through increased research activities. Robert Partridge, executive vice president and general manager of NRECA, finds EPRI particularly effective in this R&D effort. "I think that much of what EPRI has done in field R&D might not have occurred otherwise. The federal government would not have done it, nor would the utilities themselves, whether public, cooperative, or investor-owned. These research needs are larger than any one utility system."

The NRECA Standing Committee on Research and Technological Development is responsible for the evaluation and approval of the research projects supported by NRECA's research fund. A project at the University of Minnesota Agricultural Experiment Station is devoted to a study of the impact of transmission lines on agricultural land. Using funds from NRECA and the Mid-Continent Area Power Pool Environmental Committee, the project will gather data on land lost from farm production because of the presence of transmission lines. Another NRECA project at the University of Minnesota addresses the problem of stray voltages, a phenomenon that may cause farm animals to receive slight electric shocks. "On dairy farms this can result in reduced milk production since cows, sensing the tingle of electric current, are reluctant to drink water or to let down their milk," states Lowell Endahl, NRECA's manager of R&D. "In some extreme cases, dairy farms have experienced serious economic losses due to reduction in milk production." Stray voltages have been attributed to many things, including unbalanced loads causing greater neutral current flow, improper grounding of equipment, and poor electrical connections, but the sources of stray voltages are not easily detected or remedied. NRECA's two-year study will attempt to identify exactly what causes these stray voltages and recommend remedial action.

Research on irrigation load management conducted at the University of Nebraska and Kansas State University has already demonstrated how farmers can save water and energy and can shift irrigation load from daytime peak load periods to off-peak periods to take advantage of reduced rates.

Rural electric systems are also working with other utilities and DOE to field-test about 100 units of an electric heat pump water heater, which was brought to the prototype stage with initial funding by NRECA. The electric heat pump will produce hot water with one-half the energy and at one-half the cost of a typical electric water heater. Working much like a window air conditioner, the electric heat pump removes heat from a room and puts it into the water instead of exhausting it outside. "It has real potential for energy conservation across the country," explains Endahl, "and its performance is as good as a solar water heater's but at a third of the cost." NRECA research funds have also been made available to support DOE's research involving the development of the Rehm-Goshy meter. This device can give immediate readings of the rate of energy consumption, as well as accumulated consumption, and will encourage energy conservation. Six meters are being built for testing in the first phase of the project.

Other projects that are unique to the rural cooperative utilities include efforts to discover economical ways to reduce heating and cooling needs in mobile homes, which to a large extent are connected to rural electric lines. The existing insulation standards for mobile homes will be analyzed and recommendations will be made for upgrading the standards. NRECA is also participating in a study to use farm wastes to develop new fuel sources for generation.

The two most recent projects undertaken by NRECA relate to wind generation and peat-fired power plants. The wind generator study, completely funded by NRECA, will focus on the characteristics of wind turbines and generators that should be considered when these systems are connected to distribution lines. In cooperation with North Carolina systems, NRECA and EPRI are jointly funding a project on the potential of peat-fired power plants.

NRECA's research results and EPRI's projects are publicized to the rural cooperative membership in a monthly column written by Endahl for the association's monthly magazine, *Rural Electrification.* Also, the Management Services Department of NRECA sponsors continuing education programs and workshops for managers, directors, and supervisors of rural cooperatives, where the results of load management and energy conservation research are reported and discussed in terms of application to rural systems.

## Conservation R&D

The three trade associations not only support research directed at advancing current technologies but also share a common goal of increasing their members' awareness of conservation techniques. To meet the nation's current energy needs, the utility industry must encourage residential, industrial, and commercial conservation to minimize the escalating costs of building new generating plants. "Energy conservation or, as we like to call it, efficient utilization of energy has brought a whole new horizon to our R&D needs, particularly in the load management area," explains Partridge.

The three trade associations help their member utilities meet this need by providing a variety of conservation services. EEI's National Energy Watch (NEW) Commercial/Industrial Program was established last year to help large users conserve energy. The Commercial/Industrial Program complements the NEW Residential Program established in 1977, which was the first nationally organized, voluntary energy conservation effort. Utility participation in the NEW Residential Program increased to approximately 150 companies this past year and includes investor-owned and non-investor-owned electricity suppliers. The Electrification Council, a separately funded activity of EEI, provides an energy management action program for member companies. The program is a comprehensive course that details how to save energy. Member companies use the course for training their industrial, commercial, and institutional customers in the practical management of large energy systems. Fifty-five member companies have presented classes to 3000 representatives of industry and commerce.

The energy conservation services offered by APPA include an information exchange section in the APPA library that contains materials from member systems on their energy conservation or load management projects, a film library of energy conservation movies, and a slide show, "Public Power and the Conservation Challenge." APPA also publishes a variety of conservation guides, such as the *APPA Energy Conservation Manual, Utility In-House Conservation: Guidelines for Public Power Systems,* and the *Federal Energy Conservation Bibliography.* Karen Anderson, APPA's full-time energy conservation manager, works with the member utilities to aid them in developing strong conservation programs. The member utilities play a role in the association's projects through participation on the Energy Conservation Committee, in the Energy Management and Communications Workshop, and on a special ad hoc committee on the National Energy Conservation Policy Act.

Through a grant from DOE, APPA sponsored residential energy conservation workshops this past year for utilities not covered by the National Energy Conservation Policy Act. Held in 10 locations across the country, the workshops were four-day practical discussions on how to conduct communitywide residential energy conservation programs. APPA also provided follow-up technical assistance sessions. "We are quite proud of this effort," notes Radin. "We have had very good participation from the members of our association and from other small utilities, which are not required to provide some of the conservation services that are mandated by the act. The small utilities are gearing up to provide many of these services voluntarily."

At NRECA's 1977 annual meeting, delegates from nearly all the member cooperatives passed a resolution directing the association's board of directors and staff to give the highest priority to energy conservation. At that time, NRECA also established an energy conservation committee that took on the task of informing the member systems on energy conservation. In cooperation with the U.S. Department of Agriculture's Farmers Home Administration, NRECA put together a program for rural consumers to be given loans for home weatherization. These loans now total more than $1 million, with 237 cooperatives participating, and are restricted to lower-income families in nonmetropolitan areas.

To respond to the increasing interest in conservation from its members, NRECA added a full-time energy management consultant, John Mashaw, to the Management Services Department. The association now offers three-day training workshops where rural cooperative employees are instructed in conducting home energy audits and in answering consumers' conservation questions.

The Model Energy Conservation Program is NRECA's latest effort in communicating the need for conservation. This full-day workshop is designed to help managers at rural cooperatives structure their energy conservation plans to meet government regulations and train their employees for conservation activities on a continuing basis. "We here at NRECA think of conservation in a very broad sense, which is that energy conservation means not only not wasting energy but also making efficient use of what is used. We see load management as an integral part of energy conservation," indicates Partridge. There are now nearly 200 rural electric cooperatives with load management programs that feature direct-control devices, voltage reductions, and voluntary participation.

### The Legislative Connection

The R&D activities at EPRI are, of course, affected by the actions of Congress and the administration on legislation relating to power systems development and operation. The three utility trade associations are located in Washington close to Congress and the federal agencies so that they can represent their members' interests in legislative and regulatory decision making on issues of importance to EPRI, as well as many other issues of importance to member utilities. The legislative staff members of the three associations often use EPRI research results and technical reports to support the industry's views on current legislation. For example, EPRI's research has provided assistance on such topical issues as oil back-out plans, nuclear safety, breeder reactor technology, and acid rain. This last issue is quite crucial. As McCollam points out, "If in the future we don't have new coal-fired plants in addition to new nuclear plants, we aren't going to have a reliable electric supply system in this country; therefore, the acid rain issue is a very critical, current issue that EPRI's research is dealing with."

EEI moved its headquarters to Washington in 1979 to increase the interaction between the member utilities and the federal government on public policy issues confronting both the industry and the consumers of electricity. As McCollam notes, this increased interaction is one of the central goals of EEI. "Our board of directors has indicated that the principal thrust of our activities will be government affairs. I mean government affairs in a broad sense—not only dealing with Congress on legislation that is critical to our industry but also dealing with the myriad government agencies charged with implementing legislation once it is enacted."

The Governmental Affairs Group of EEI, headed by Frederick L. Webber, executive vice president, is divided into three functional areas: legislative affairs, coordination with federal agencies, and public policy planning. The group not only provides for expert testimony at congressional hearings but also oversees preparation of written and oral comments on agency rule-making activities often handled by other groups. To help member company executives keep abreast of legislative events, the Governmental Affairs Group publishes a weekly newsletter, the *EEI Washington Letter,* that provides a summary of pertinent legislative and regulatory events scheduled for the week ahead. Published with the *Letter* is the Legislative Status Chart, which contains information on the status of key legislation in Congress.

The staff of the legislative section of APPA, headed by Alan Richardson, works on a variety of congressional and regulatory issues to encourage domestic energy independence. The legislative staff also monitors any congressional activity that affects the marketing of federal power. Public power utilities, as a group, are the largest single purchaser of electricity from the federal agencies. "Most of the legislative issues that we are involved with relate to power supply in one way or another," explains Radin. "We are constantly on the lookout for any changes in laws that affect our access to power built or marketed by federal power agencies. We are also concerned with the access to power plants or facilities built by investor-owned utilities."

APPA also represents its members' views on such issues as nuclear waste disposal, energy assistance programs, and railroad deregulation policy. This last issue is significant to APPA because one of its member utilities, the city of San Antonio, Texas, is often cited as an example of a utility held captive by a railroad that transports coal. Without the regulation of rail rates, the railroads can set any price the traffic will bear.

NRECA's legislative activities are conducted by its Government Relations Department, which is under the direction of John Davenport. The government relations staff is responsible for securing favorable responses from Congress on bills affecting energy and rural America. NRECA encourages the members of rural electric cooperative statewide associations and the individual rural electric systems to lobby on a grass roots level to keep their congressmen informed of their concerns. A NRECA-sponsored legislative conference, held each spring in Washington, is attended by more than a thousand local rural electric leaders, who visit members of Congress and express their views on current legislation.

One particular legislative issue that the rural cooperatives have a vital interest in, as do the other two utility associations, is the authorization for the funding of nuclear power plants. As Partridge emphasizes, "We have been involved financially with the Clinch River program from the beginning, and we believe that the sooner the project is built, the better. We feel the breeder is a must for this country. If conservation means anything, we should be conserving uranium ore through the use of the breeder."

Although the three associations share many of the same legislative concerns, their focus differs in other areas as each organization strives to fulfill the particular needs of its members. Partridge speaks for all three associations when he says, "We essentially provide the kinds of services our members need at the lowest possible cost and with the highest possible quality." ■

# French Delegation Confers on Breeder

Pronounced differences of opinion were found between the public and private sectors on the strategic role of the fast breeder reactor and its potential contribution to nuclear proliferation.

Led by Pierre Messmer, former prime minister of France, members of the French Parliament and French journalists met with EPRI scientists recently. The EPRI visit was part of the French delegation's week-long fact-finding mission in the United States. Members of the group were especially interested in prospects for U.S. energy conservation and a rejuvenated fast breeder reactor (FBR) program. In particular, they noted the differences of opinion between Washington officials and leaders of the U.S. energy industries on the question of the FBR and nuclear proliferation.

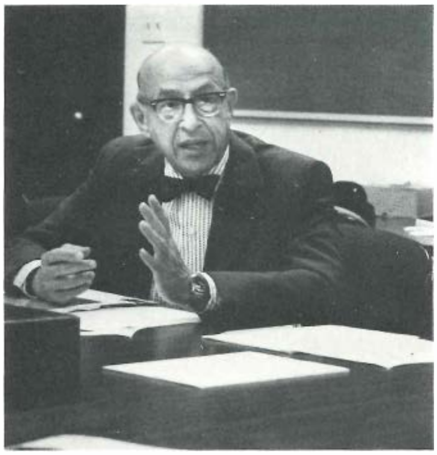
Richard Rudman, director of EPRI's Policy Planning Division, told the delegation that by the year 2000 the United States can expect to achieve 20% total energy conservation, a departure from the historical trend. He added, however, that nuclear energy must be the swing-fuel for the United States or shortfalls in electricity will occur by the 1990s.

Chauncey Starr, EPRI vice chairman and director of the Energy Study Center, discussed the uncertainties of uranium supply, which will bring about a need for the FBR. According to Starr, the United States may have enough domestic uranium resources to do without the breeder for 25 or 30 years, but France will require it before the end of the century. Political perceptions of the importance of secured energy supplies may advance these dates.

In answer to questions from members of the French group, Milton Levenson, director of the Nuclear Power Division, said there is no technical basis for believing the FBR is inherently more expensive or proliferation-prone than the light water reactor (LWR). Present cost comparisons are distorted because the FBR is in the development stage, whereas LWR technology is in its third generation of use. Levenson also noted that the costs of fuel, availability of fuel, and reprocessing are very important considerations.

In a dialogue with Messmer, which was filmed by a French television crew, Starr reiterated these points. He also commented that the potential for exacerbating proliferation is about the same for LWRs and FBRs, and either technology would be a particularly inefficient way to produce material for nuclear weapons. Clandestine reprocessing of diverted spent fuel is the weak link in any nuclear proliferation scheme. A potentially easier


Messmer


Starr


Levenson

and less readily detected method of obtaining fissionable material would be uranium enrichment in a small, dedicated facility. As that option is totally independent of the FBR fuel cycle, Starr believes proliferation must be dealt with primarily as a diplomatic problem. ■

## Coal Wastes Become Artificial Reef

An artificial reef consisting of 500 t of wastes from coal-fired power plants has been built at Fire Island, New York, off Long Island's south shore. The reef is expected to enhance biological productivity and sportfishing opportunities in the area, as well as demonstrate a promising new method for disposal of coal wastes.

As U.S. utilities substitute coal for imported oil in power generation, the problem of waste disposal is likely to become critical. A large power plant may produce 100 t of solid coal wastes each day. In the Northeast especially, there will be little room for disposing of such large amounts in landfills or sludge ponds.

Marine researchers have long been experimenting with the use of artificial reefs to increase coastal fisheries. Materials ranging from building rubble to Liberty ships have been sunk in shallow waters to provide new habitats for marine organisms.

In earlier stages of this project, tests on a smaller scale were conducted to show that fly ash and sludge from stack gas scrubbers could be cast into concretelike blocks. Underwater tests were conducted on a small number of blocks to make sure no toxic substances leached into the environment. The full-scale demonstration now under way is needed to prove the environmental suitability and economics of this means of disposal.

Some 15,000 blocks, weighing 60–70 lb each, were stacked in waters 65 ft deep. The 12-ft-high submerged reef was constructed with irregular contours to provide hiding places for small fish. Regular surveys of the reef will be conducted by scientists from the Marine Science Research Center of the State University of New York at Stony Brook during the next several years. The surveyors will study biological colonization and monitor the stability of the blocks. It is expected that the blocks will remain more stable than most materials previously used in artificial reefs.

This five-year project cosponsored by EPRI marks the first major effort at seabed disposal of coal by-products. EPRI is sponsoring research to determine how the economics of seabed disposal compare with other disposal methods. (Other disposal methods, such as the production of marketable gypsum from coal wastes, are being explored, but none are likely to be sufficient for the vast quantities of material involved.) Funding for this work is also being provided by a group of federal and New York state agencies, according to EPRI Project Manager Dean Golden. ■

## Shearon Harris Dies

Shearon Harris, one of the utility leaders who engineered the formation of EPRI, died August 28 following a lengthy illness. He was 62.

Harris was president of the Edison Electric Institute in the early 1970s, a time when electric utilities were beginning to realize that the industry required greater R&D efforts than the manufacturing sector could provide. It was also realized that if the utility industry did not make these efforts, the federal government would. Prompted by the 1965 Northeast blackout, senators Warren G. Magnuson and Ernest F. Hollings proposed federal legislation that would establish a government agency to carry out industry R&D, paid for by a tax on utilities.

Armed with a 1971 Electric Research Council report on utility R&D goals, Harris courted the National Association of Regulatory Utility Commissioners and won a resolution that paved the way for a utility-operated organization to perform the needed R&D. Harris next went before the Magnuson committee and gained one year's time to put the organization together. He then successfully campaigned for strong support of the new organization among investor-owned, public, and cooperative utilities. With the selection of Chauncey Starr as president in 1972, EPRI began operation. "Shearon was a close and staunch colleague during the years in which he helped develop the Electric Power Research Institute," recalls Starr. "I had great admiration for his brilliance and human qualities. We will miss him."

Harris joined Carolina Power & Light Co. as associate general counsel in 1957. He was named a vice president of CP&L in 1960, member of the board of directors in 1961, and general counsel in 1962. He served as president of CP&L from 1963 to 1976, chief executive officer from 1969 to 1979, and chairman of the board from 1970 to 1980. Harris stepped down as chairman in May 1980, but continued as a member of CP&L's board. He was chairman of EPRI's board of directors from 1975 to 1977. Harris is survived by his wife and three daughters. ■

## CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

**DECEMBER**

**2–4**
**Utility Seminar on the Use of Coal in Oil Design Utility Boilers**
Lake Buena Vista, Florida
Contact: Steven Drenker (415) 855-2823

**10–11**
**Seminar on Environmental Risk Assessment: How New Regulations Will Affect the Utility Industry**
New Orleans, Louisiana
Contact: Phyllis Kemper (509) 375-0663

**JANUARY**

**21–22**
**Seminar on Prevention of Failures in Condensers**
Palo Alto, California
Contact: Barry Syrett (415) 855-2956

# R&D Status Report
# ADVANCED POWER SYSTEMS DIVISION

Kurt Yeager, Director

## COAL GASIFICATION PILOT PLANTS

*Coal gasification–based systems offer distinct environmental advantages over conventional direct-coal-fired plants with flue gas cleanup because emission-forming constituents are removed before the combustion process. Plants integrating coal gasification with combined-cycle power generation will be more efficient and use less water than direct-coal-fired units. Studies show that when designed to current emission standards and equipped with commercially available combustion turbines, such integrated gasification–combined-cycle (GCC) plants will be economically competitive with direct coal firing. If emission standards become more restrictive, the competitive position of GCC technology will be further enhanced. Also, there is a great deal of potential for improvements in both coal gasification and combustion turbine technology. Toward the goal of more efficient and less costly systems, EPRI's Clean Gaseous Fuels Program is supporting the development of three major second-generation coal gasification processes. Background on these processes and schematics of the basic gasifier designs are given in an earlier* Journal *article (January/February 1979, p. 37).*

The three EPRI-supported coal gasification processes are being developed by Texaco, Inc., British Gas Corp. (BGC), and Combustion Engineering, Inc. (C–E). Pilot plants based on these technologies are operating with coal capacities greater than 100 t/d. Results from test runs at these plants and other units indicate the suitability of the technologies for utility application and provide the basis for scale-up to commercial-size demonstration units (with a coal capacity above 1000 t/d) in the mid-1980s.

Each of the technologies draws on a background of relevant commercial experience. Texaco's gasifier is very similar to its oil gasification units, about 160 of which have been built. The BGC-Lurgi slagging gasifier is an improvement on the commercial dry-ash Lurgi process. The C–E gasifier is similar in certain respects to the earlier Babcock & Wilcox Co. and Rummel gasifiers that operated commercially in the 1950s and to C–E's pulverized-coal-fired boilers.

### Texaco entrained gasifier

For several years, Texaco has been developing a pressurized, single-stage, downflow, entrained gasifier fed by a highly concentrated coal-water slurry. A variety of U.S. coals have been tested at the 15-t/d pilot plant at Montebello, California.

The gasifier at Montebello, in combination with a Selexol system for sulfur removal, has been subjected to a series of transient tests and steady-state runs at different turndowns (RP985-1). The clean product gas from some of the steady-state runs has been burned in a United Technologies Corp. gas turbine combustor. Also, the various process streams and effluents have been analyzed to assess potential environmental impact.

In the fall of 1978 a scoping run was conducted to develop sampling and analytic methodologies. The following summer two runs were performed—the first used pure oxygen as the gasifying medium; the second used enriched air. In both runs Illinois No. 6 coal was the feed. In April 1980 an additional oxygen-blown run was conducted to enable data verification and additional transient tests.

Test results indicate that the gasifier responds nearly instantaneously to load changes and the product gas remains essentially unchanged during transients. The analytic studies show the Texaco technology to be a clean, environmentally sound process for the use of coal. Specifically, the studies yielded the following results.

- Particulate loadings in the product gas were negligible. Most filters showed less than 0.1 mg/m³ (normal). The mean size of the particles was ~0.3 μm.

- It is anticipated that the effluent water from the process will require minimal treatment to meet effluent standards, although such standards have not yet been established for coal gasification plants. The average concentrations of toxic elements detected in the water are well below EPA drinking water standards except for arsenic, iron, lead, manganese, and selenium and meet the EPA and California standards for solid-waste leachates.

- The only mononuclear aromatic compounds detected in the effluent water were benzene (~30 ppb) and toluene (~20 ppb). These concentrations fall below the proposed EPA limit of 50 ppb for these compounds in petroleum-refining effluents. A few polycyclic aromatic hydrocarbons were detected but at insignificant levels (~1 ppb).

- Ammonia levels in the product gas were ~2–10 ppm.

- No buildup of organics or metals in the Selexol solvent was detected. The runs were considered to be sufficiently long for these impurities to reach equilibrium.

- Leaching tests on the slag with deionized water (in accordance with procedures laid down by ASTM and the states of California and Texas) produced leachates that fell at least an order of magnitude below the proposed EPA regulations under the Resource Conservation and Recovery Act. In fact, except for three trace elements, the leachates even met the EPA drinking water criteria.

In January 1978 a 150-t/d Texaco unit began operation at Ruhrchemie Ag's plant in Oberhausen, Federal Republic of Germany. This project is sponsored by the West German Federal Ministry of Research and Technology (60%), Ruhrkohle Ag, and Ruhrchemie. Over 4000 hours of operation with five German coals have been completed to date (including an 800-hour run). The results confirm the success of the tenfold scale-up from the Montebello pilot plant to the German unit. An additional development being tested on the Ruhrchemie unit is a heat recovery steam boiler at the gasifier outlet. This equipment is particularly important for configuring an efficient GCC plant.

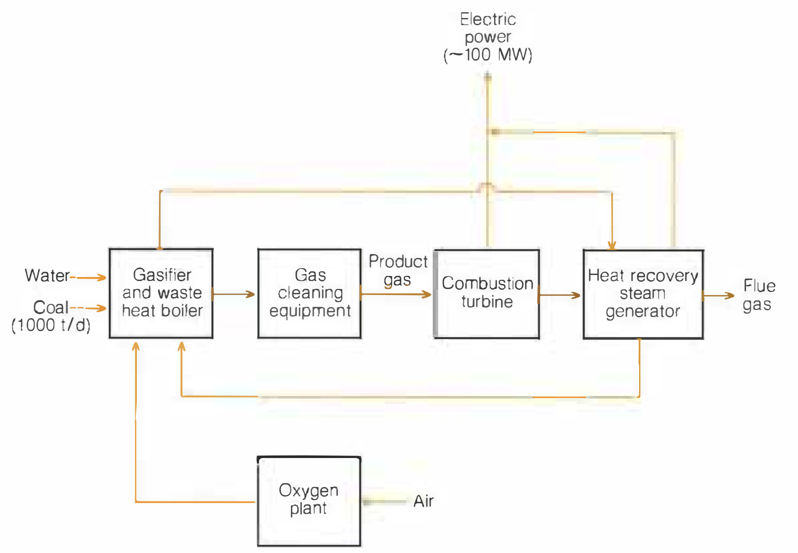
EPRI has negotiated an agreement with Ruhrchemie and Ruhrkohle for a series of tests at the Oberhausen unit, using Illinois No. 6 coal, the same coal used in the Montebello tests. The Oberhausen tests are planned for late 1980 and early 1981 (RP1799).

Another 150-t/d Texaco unit, which will produce feedstock for an ammonia plant, is under construction for the Tennessee Valley Authority at Muscle Shoals, Alabama. This unit does not include heat recovery. A unit of similar size was completed for Dow Chemical Co. at Plaquemine, Louisiana, in 1979, but little information on its performance is expected to be publicly available.

After the successful scale-up of the coal gasifier, Texaco and Southern California Edison Co. (SCE) proposed a 100-MW integrated GCC demonstration plant (Figure 1) at SCE's Cool Water station near Barstow, California. The total cost of the project, covering design, construction, and initial operation, is currently estimated at $300 million. EPRI has entered into a participation agreement to contribute $50 million (RP1459). The design of the plant is well under way, and startup is scheduled for late 1983. Additional funding is being pursued by the participants. Assuming the successful demonstration of the integrated GCC plant by 1985, full-scale commercial units are projected to begin operation about 1990.

A feasibility study contract for a ~500-MW GCC plant based on the Texaco technology at a Central Maine Power Co. facility was recently awarded by DOE.

Figure 1 Process flow in the proposed 100-MW gasification–combined-cycle demonstration plant funded by EPRI, Texaco, Southern California Edison, and others.




## BGC–Lurgi slagging gasifier

Lurgi dry-ash gasifiers use excess steam to keep the ash below clinkering temperature. The BGC-Lurgi slagging gasifier is deliberately operated well above this temperature, which dramatically reduces the steam consumption (by 80–92%) and increases the throughput, leading to greater efficiency and less wastewater production. The solidified slag has been classified as a nonhazardous waste by EPA. In addition, the tars that are produced in any countercurrent moving-bed gasifier can be completely gasified by injection through the tuyeres.

From 1975 to 1977 EPRI and 13 U.S. oil and gas companies supported the development of the BGC-Lurgi slagging gasifier at Westfield, Scotland. In this project a commercial Lurgi dry-ash unit was converted to operate as a slagging unit, and a 23-day run at 13 t/h was conducted (RP407).

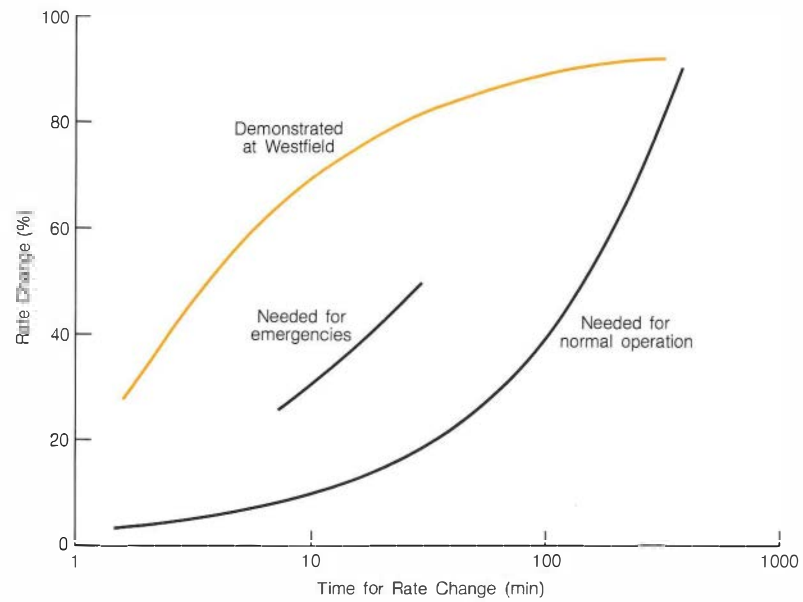
In 1976 Conoco Coal Development Co. proposed a high-Btu gas demonstration plant based on the BGC slagging technology. DOE has fully funded this proposal through the design phase, which will be completed in June 1981. At that time DOE will decide whether to fund this plant or one based on COED-Cogas technology proposed by the Illinois Coal Gasification Group (or both). As part of the Conoco project, which EPRI joined as a cosponsor, test runs of up to five days were conducted at Westfield with high-caking U.S. coals—Pittsburgh No. 8 and Ohio No. 9 (RP1186).

Following this successful test program, EPRI, BGC, and Lurgi conducted a series of tests at Westfield in late 1979 to determine the slagger's ability to meet U.S. utility load change requirements. Before the tests, the plant control system was completely revamped to a configuration considered the most suitable for a combined-cycle application. Monitoring devices were upgraded to ensure high-confidence measurements of heat and mass balances, and instruments were added for continuous monitoring of the product-gas heating value to detect fluctuations during load changes.

The feed for the first run was a British coal that seems to be similar in all important respects to Illinois No. 5 or No. 6. (Conoco is now conducting a series of special coal characterization tests to verify this.) Although the run was scheduled primarily for the commissioning of the new control system and instrumentation, stable operation was achieved over the entire range of 30–115% of rated load. Some rapid production rate changes were also made.

The second and third runs were conducted on Pittsburgh No. 8 coal, whose high caking and swelling properties make it a particular challenge for moving-bed gasifiers. Stable operation was consistently achieved during extended runs covering 30–100% of rated load. Rate changes were made much faster than required for normal load management and faster than required for most system emergencies (Figure 2). Fluctuations in product-gas quality were insignificant during even the most rapid rate changes, and the new control system for combined cycles performed better than expected throughout the runs. In addition, the runs consolidated the results of previous tests by providing an extended demonstration that the gasifier can operate with up to 25% fine coal in the feed (continuous mining can produce up to 50% fine coal), net tar production can be completely gasified by injection through the tuyeres, and the gasifier can use readily available limestone flux (a modest amount of fluxing agent is necessary

Figure 2 Demonstrated response rates of the BGC-Lurgi slagging gasifier at Westfield, Scotland, in runs of 30–100% rated power with Pittsburgh No. 8 coal.




to reduce the viscosity of some slags).

During the 17 days of operation, 3800 tons of coal were gasified. Coal consumption was this low because the gasifier was intentionally operated below its demonstrated capacity (350 t/d) about 75% of the time. The gasifier's efficiency, its turndown and load-following capabilities, and its short-term operability were impressive. Still to be demonstrated are its durability over the long term, its ability to operate on a larger scale, and its ability to handle higher percentages of fine coal and a wider range of coals, including low-rank western U.S. coals. A program to test the injection of fine coal through the tuyeres in the Westfield unit is already under way, and a larger-diameter gasifier is scheduled to be operational by 1982. BGC's commitment to addressing these issues is encouraging, as is the fact that DOE has awarded a contract for design and cost estimation for a GCC plant using the BGC-Lurgi technology for Florida Power Corp.

### C–E entrained gasifier

EPRI is participating in the design, construction, and testing of a gasification process development unit (PDU) at C–E's Windsor, Connecticut, facilities (RP244-1). Gasification is accomplished in a two-stage atmospheric entrained unit. With a design capacity of 5 t/h, the PDU is the largest pilot gasifier in the United States.

In addition to the gasifier itself, the PDU includes a coal preparation section; convective gas coolers that extract heat from the hot product gas leaving the gasifier; a particulate removal system that recycles unconverted char to the bottom combustion zone of the gasifier; a Stretford system that removes hydrogen sulfide from the product gas and converts it to elemental sulfur; and a package boiler in which the clean product gas is ultimately burned, providing preheat for the gasifying media.

The PDU was dedicated in October 1977; because of a severe winter, startup and shakedown tests lasted until May 1978. The first run, in which Pittsburgh No. 8 coal was gasified by air, was conducted in mid-May 1978. The test program called for a systematic series of parametric tests to define the range and capabilities of the gasifier in steady-state and transient operation, followed by a sustained endurance run. This program has yet to be completed. The PDU has run into several problems, as often happens in the early stages of a large experimental project. One by one, these problems have been identified and overcome. In the course of this work, the PDU has logged over 2500 hours of gasification operation, including several continuous runs of 10–13 days. These runs have demonstrated the basic features of the C–E process: production of a gas free of tars, discharge of essentially inert slag, and stable operation at part load. The plant is easy to run and to control.

However, yet to be demonstrated is routine operation at full design capacity with production of a product gas of satisfactory quality. Much of the operation to date has been conducted at rates well below the full design capacity, and the heating value of the product gas has typically been ~50–70 Btu/ft³ (1.9–2.6 MJ/m³). The key obstacles to full-load operation and a better gas are high heat losses in the combustion section (aggravated by refractory wear) and poor fuel utilization in that section. C–E has just completed substantial modifications in the combustion zone, including the installation of new burners designed to promote a better mixing of fuel and air. C–E also plans to launch supporting studies to investigate burner design, the reactivity of coals and chars, and combustion under conditions like those prevailing in the gasifier.

If it can be successfully developed, the C–E technology offers the benefits of design simplicity and low-cost construction, a product gas with no tars (which eliminates the need for complex downstream processing), and feedstock flexibility. EPRI and DOE have taken the necessary steps to continue support of the C–E gasification development effort through early 1982. (DOE provides about 66% of the funding, EPRI about 20%, and C–E the balance.) The program calls for completion of the current series of air-blown tests on a Pittsburgh coal (including a 30-day sustained run); introduction of equipment to enable tests with air enriched by oxygen; and comprehensive tests on four additional coals, using both air and enriched air. Gasification by enriched air should enhance the performance of the C–E technology in both retrofit and combined-cycle applications. An air-oxygen mixture containing 38% oxygen is projected to yield a product gas with a heating value of 160–165 Btu/ft³ (5.95–6.14 MJ/m³) from a Pittsburgh coal. In contrast, gasification of the same coal by air will produce a gas with a heating value of ~110 Btu/ft³ (4.1 MJ/m³).

In May 1978 DOE selected a proposal for a fuel gas demonstration plant based on the C–E technology. A contract for the Phase 1 design, to be funded entirely by DOE, has recently been signed. Fuel gas from the proposed plant would be used in a retrofitted 150-MW natural-gas-fired boiler at the Lake Charles, Louisiana, plant of Gulf States Utilities Co. *Program Manager: Neville Holt*

# R&D Status Report
# COAL COMBUSTION SYSTEMS DIVISION

Dwain Spencer, Director

## HEAT REJECTION

*EPRI heat rejection research focuses on four primary objectives: demonstration of water-conserving cooling systems, development and validation of predictive models for discharge plumes, development of performance models and test procedures for cooling towers and ponds, and development of design guidelines for intake structures of once-through cooling systems. Background information on cooling technologies is in the October 1979* EPRI Journal *(p. 6).*

### Water-conserving cooling systems

EPRI's main endeavor in this area is development of a demonstration facility for advanced wet-dry cooling technologies (RP422). Currently under construction at Pacific Gas and Electric Co.'s Kern power plant in Bakersfield, California (Figure 1), the EPRI facility will use air-cooled heat exchangers, with water for supplemental cooling. The facility will also feature a steam condenser with heat transfer enhancements to improve efficiency. The system, which uses ammonia as the working fluid, offers potential annual savings to the industry of about $1 billion over commercially available wet-dry technology.

Following completion of the facility, scheduled for 1981, a three-year test program is planned. Operation and testing will be funded by DOE, EPRI, and a consortium of U.S. and overseas utilities. Close cooperation is being maintained through an information exchange agreement with Electricité de France, which is building a similar demonstration facility near Paris. Related efforts by other researchers include exploring variations on the basic heat rejection cycle, such as a capacitive heat rejection system and a binary cycle that produces supplemental power for winter peaking.

In a companion project, performance testing of a commercial wet-dry cooling tower has been completed by Southern California Edison Co. at its San Bernardino station (RP738). A water saving of 20% was achieved during the testing, and a further saving should be possible under optimal operating conditions. This effort included

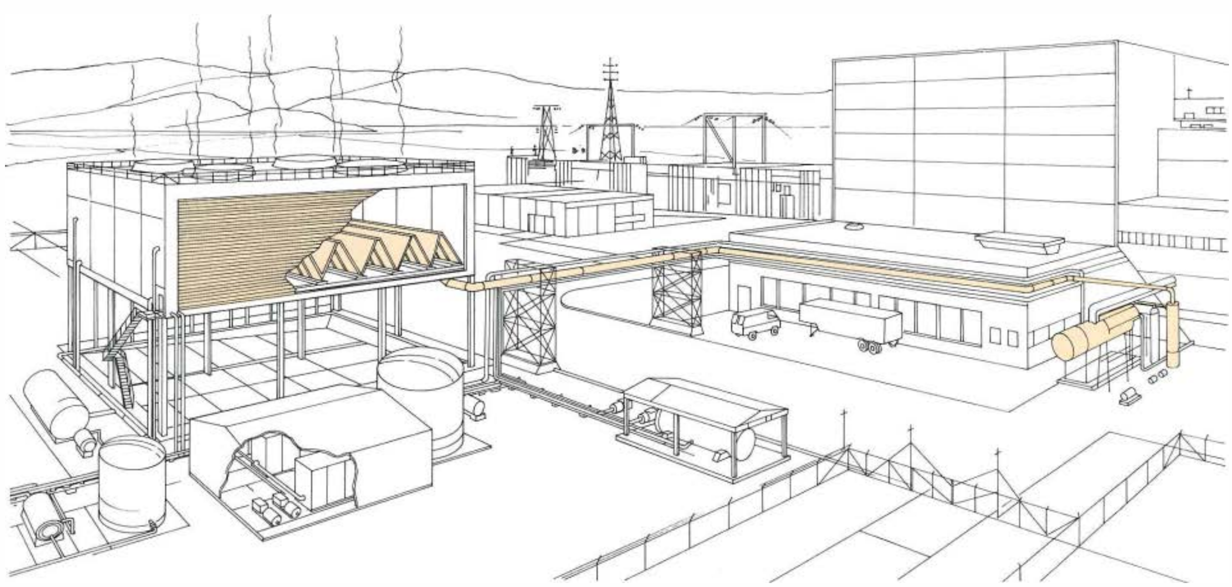


Figure 1 EPRI demonstration facility for advanced wet-dry cooling technologies. Note the air-cooled heat exchangers in the cooling tower (left), the condenser-reboiler (right), and the piping that circulates the ammonia. The sketch is based on final design drawings. Construction is under way, and testing is scheduled to begin in 1981.

the validation of a predictive model for wet-dry cooling-tower performance developed by PFR Engineering Systems, Inc., under EPRI funding. The final report will be released this month (CS-1565).

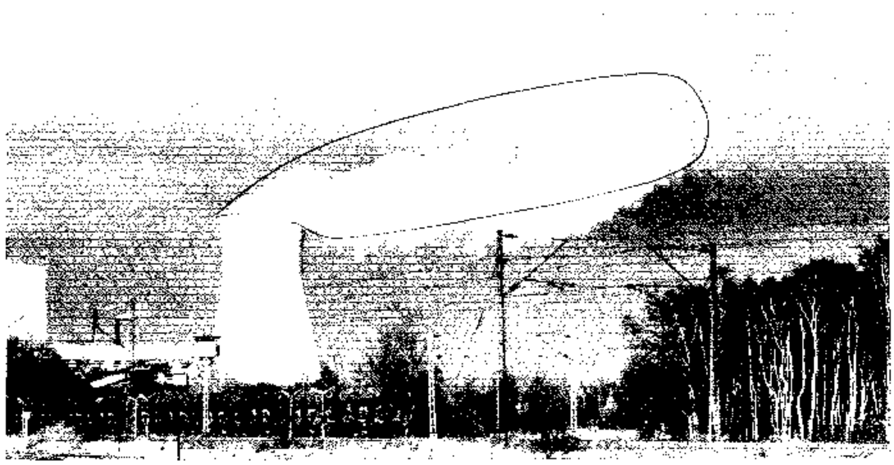
Evaluating the cost of using dry or wet-dry cooling must include consideration of the costs of reduced capacity and efficiency at the plants on which they are installed. These costs are closely tied to utility expansion plans, load projections, and system economics. Under RP1182, Dynatech R/D Co. developed a technique that accounts for these factors in the design methods and operating strategies for wet-dry cooling systems. This technique was demonstrated in a case study of a 1000-MW (e) coal-fired baseload station. The results, reported in FP-1096, indicated that using available cooling water in an optimal manner would save $650/MW annually. An analysis was subsequently performed on cycling plants, which represent about one-third of the plants now being designed (CS-1474). It was found that the effective value of cooling water may be more than 50% greater for a cycling plant than for a baseloaded plant. A user's manual for the computer simulation program is being prepared.

**Models for predicting plume behavior**

In research at Argonne National Laboratory, mathematical models of plumes discharged from cooling towers, both natural draft and induced draft, are being improved for utility use (RP906). A prediction of one computer model is compared with the results of a full-scale field test in Figure 2. Research to date is summarized in a five-volume report to be published by EPRI this year. Work in progress is aimed at developing a generalized model (with single-tower and clustered-tower submodels) to predict the seasonal and annual frequencies of visible plume impact, droplet drift, ground fogging, and icing of surrounding terrain. Another effort involves the development of methods to generate statistically reliable predictions of weather and tower operating conditions on the basis of data typically available to siting engineers. The objective of this effort is a flexible, reliable tool for use in environmental impact and plant siting studies.

This analytic work is complemented by related laboratory studies. At the Massachusetts Institute of Technology (MIT), a wind tunnel has been constructed to evaluate various methods of plume droplet drift measurement against a calibrated reference method that is being developed; the evaluation program is scheduled to begin this fall (RP1260-11). In work recently completed at

Figure 2 Comparison of observed cooling-tower plume with model prediction. On the basis of data on local meteorologic and tower exit conditions, the computer model predicts the trajectory of the visible plume and the resulting deposition of drift droplets on the surrounding terrain.



the University of Iowa's Institute of Hydraulic Research (IHR), laboratory tests were performed on hydraulic scale models of mechanical-draft cooling towers to determine plume recirculation and interference effects between towers (RP732). The results of these water flume experiments are reported in CS-1370 and CS-1547. This testing technique represents a useful and relatively inexpensive tool for tower siting studies by utilities. Such a physical modeling effort was recently performed for the Tennessee Valley Authority by IHR.

**Modeling and testing cooling-system performance**

Under RP1262 performance models of cross-flow and counterflow natural-draft cooling towers have been developed and validated by CHAM of North America, Inc. (FP-1279, 2 vols.). The computer code is currently being used by utilities in cooling-tower performance studies. Work to extend the code to mechanical-draft cooling towers is now in progress at CHAM, and a model validation is planned as part of this effort.

The Ralph Parsons Laboratory at MIT is continuing an effort to improve the ability to predict cooling-pond performance and evaporative loss (RP1260-17). After a review of available test data and evaporative loss formulations, a workshop was held in September to identify promising field measurement techniques. This project includes a scoping study for a field test program.

**Once-through cooling**

Several projects are under way that focus on the entrainment and entrapment of aquatic species in once-through cooling systems and on changes in intake design to alleviate these problems. A porous dike intake structure at the Brayton Point station of the New England Electric System is being tested by New England Power Service Co. and Marine Research, Inc. (RP1181). Results to date indicate that no serious clogging or fouling problems have occurred. The second year of laboratory work and field tests is in progress. In a related effort at Oak Ridge National Laboratory, a series of entrainment mortality studies is being conducted, using a condenser simulator; this work will continue into 1981 (RP1183).

As part of a project on screening systems for power plant intakes, a clearinghouse is being organized for the collection, analysis, and dissemination of biological data, information on operating experience and problems, and engineering and cost data. Finally, a project to develop field-validated analytic models for use in transient design calculations for circulating-cooling-water systems is continuing at the Georgia Institute of Technology (RP1342). Currently, field test results are being compared with the predictions of a mathematical model.

**Cooling-tower workshop**

A workshop organized by EPRI and the International Association for Hydraulic Research was held in San Francisco in September. Over 60 specialists from 10 countries discussed the results of recent research on cooling-tower performance and environmental considerations. The workshop was followed by an inspection of the wet-dry cooling-tower installation at the San Juan 3 site near Farmington, New Mexico. The workshop proceedings are being prepared for publication. *Subprogram Manager: John A. Bartz*

# R&D Status Report
# ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

## OVERHEAD TRANSMISSION

### Insulator flashovers on HVDC lines

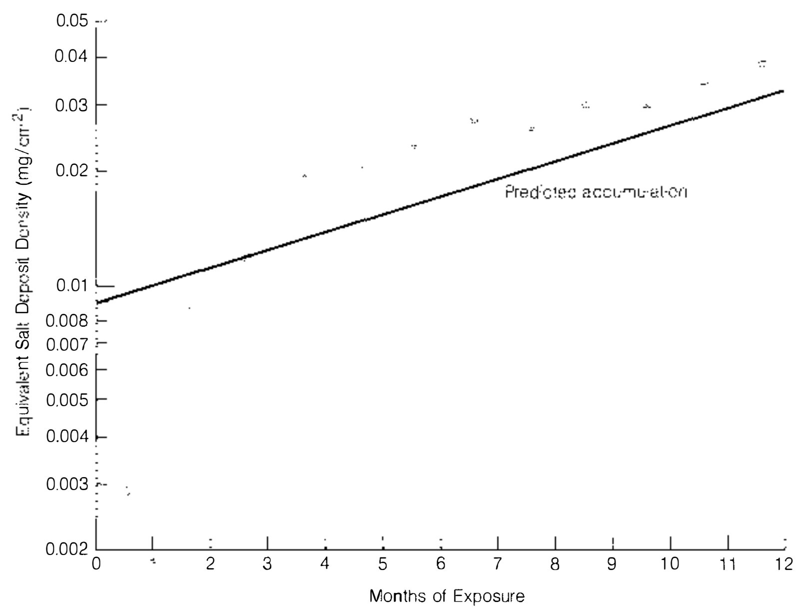
One of the most perplexing problems facing operators of HVDC transmission lines is insulator flashover. This problem can be serious for ac lines, but it is even worse for dc. In spite of years of work to identify the cause of flashover, the phenomenon is still not fully understood.

Researchers at the University of Southern California (USC) have observed an interesting phenomenon that occurs on the insulator test rack maintained by the Los Angeles Department of Water & Power at the Sylmar converter station (RP848). Here leakage current and weather conditions are recorded concurrently for insulator strings tied directly to one conductor of the ±400-kV Pacific Intertie Line.

Two major factors that determine flashover of a string of insulators are surface contaminant and atmospheric moisture. By analyzing the pattern of insulator leakage current and relative humidity (RH), it has been observed that the leakage current under the conditions existing at Sylmar increases dramatically when RH is above 80%. It has also been noted that the rate of accumulation of surface contaminants on a string of insulators is fairly predictable (Figure 1).

Analysis of the Sylmar recordings suggests the possibility that flashover on HVDC lines can be predicted. If predictions could be keyed to observations of contaminant accumulation and leakage current at a threshold RH, operators could take precautionary measures to prevent flashover—for example, by lowering the voltage on the dc line. The possibility of predicting flashover is still being analyzed by USC; however, preliminary investigations indicate that such predictions may be possible. Refinement of prediction methods and other investigations of HVDC insulator contamination and flashover will continue through 1980, and results will be published in early 1981. *Project Manager: John Dunlap*

Figure 1 Data points represent measurements of contaminant accumulation on the undersurfaces of insulators at the Sylmar converter station in 1979. These measurements correspond well to an accumulation rate prediction theory developed in 1977.



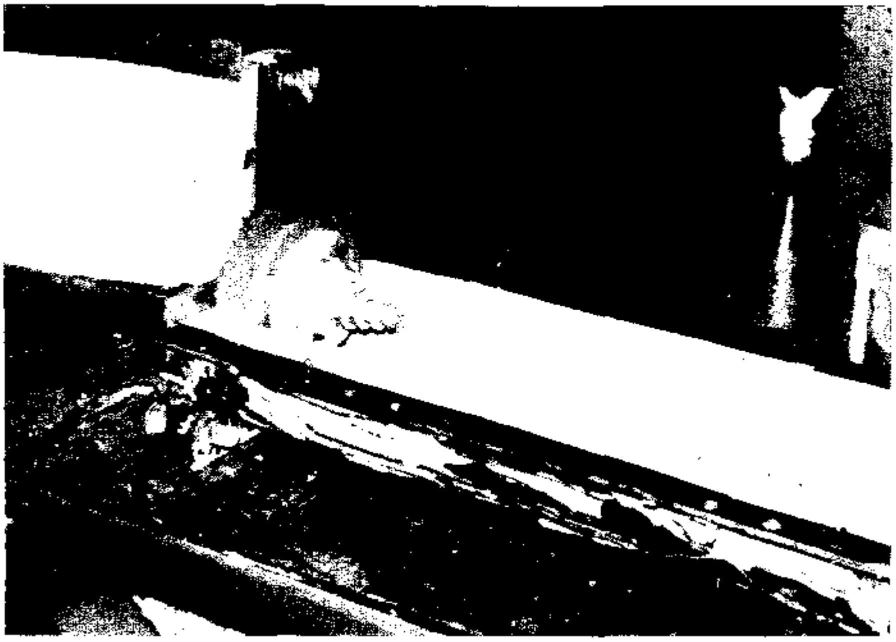

### Polysil* insulator field evaluation

For the past three years EPRI has funded the development of a new insulating material, Polysil, which appears to be suitable for outdoor applications (RP1280). This material is approximately 90% silica in various granular sizes for maximum compaction, bound together by a monomeric resin that is polymerized after mixing. The resulting material provides higher mechanical and dielectric strengths than the bulk form of either of its constituents. The material is molded and polymerized without external heat, and the capability to encapsulate metal in the material during the molding process allows insulator designs not possible with porcelain.

The end caps for prototype insulator designs vary from simple individual metal thimble inserts to deeply imbedded inserts that provide both mechanical attachment and voltage grading near the insulator ends. One of the purposes of the end caps is to transfer the high electrical stress normally experienced at the interface of the metal and air into the Polysil; the stress then appears at the interface between the metal and the Polysil, which has a much higher dielectric strength than the outside air (Figure 2). This should result in suppressed corona and thus

*Polysil is an EPRI trademark.

Figure 2 End cap positioned in a Polysil insulator mold before pouring. Imbedment of the end cap tends to give a graduated electrical stress pattern, thereby spreading the stress at the top of the insulator and reducing corona.



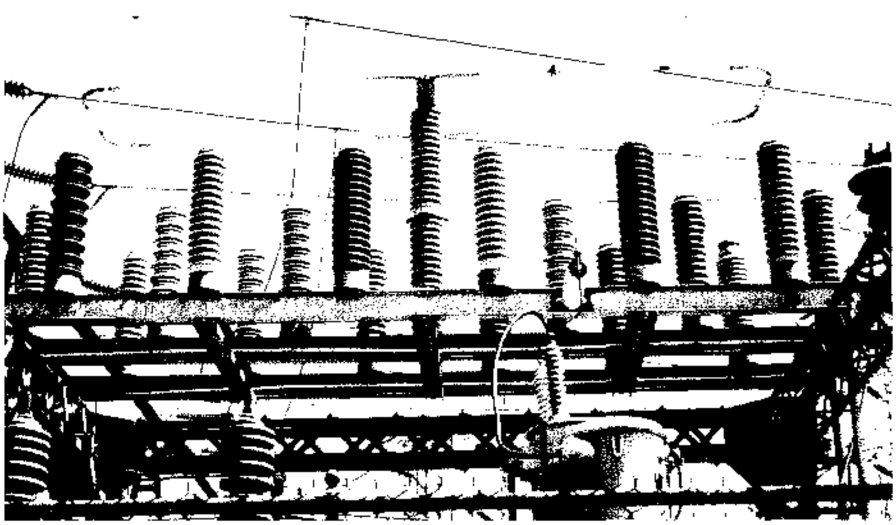


Figure 3 Polysil insulator test rack installed and energized at 69 kV in a substation of Los Angeles Department of Water & Power. Similar racks are installed at 24 other utility sites across the United States and Mexico.

fewer air ionization and tracking problems than encountered with conventional insulators. Because Polysil insulation has a coefficient of thermal expansion and contraction that is very close to that of aluminum and is an extremely good adhesive, little problem is expected with this design.

A comprehensive field evaluation program is now under way to assess the capabilities of Polysil insulation for outdoor applications under a wide variety of environmental conditions. In this study, 25 instrumented racks of 69-kV insulators are being energized on systems throughout the United States and Mexico; the test sites were chosen to represent as wide a range of environmental conditions as possible. Each of the racks holds 17 post-type Polysil insulators and 1 standard porcelain insulator, which is used as a control (Figure 3).

Instrumentation attached to the insulators will record various types of surface currents and correlate these with atmospheric conditions. In addition to the insulator rack tests, nonenergized flat samples of the various Polysil formulations will be used to collect contaminants, which will be analyzed periodically in laboratories.

This field evaluation program will provide information on much more than the material itself. Most outdoor insulator test sites are located in coastal areas, where the air has high salt and moisture contents. As these conditions are not typical of all the locations at which insulators will be used, the designs and configurations that are optimized at coastal sites will not necessarily be the most economical and optimal for application in other environments. For example, heavy fog conditions may dictate a deep undercut on the insulator skirts; however, evidence from dry areas appears to support the theory that skirts with no undercut provide a more washable surface, which results in less contamination and, consequently, fewer flashovers. In the past, sufficient data have not been available to resolve such problems of design and environment. The Polysil test program is designed to gather these data in a scientifically acceptable manner.

It is expected that results of these tests will provide utilities with information on the insulator materials, designs, and surfaces that are most suitable and economical for their particular local environmental conditions. *Project Manager: John Dunlap*

**Control of line galloping by detuning**

Galloping of transmission line conductors has been monitored for the third successive season by 35 electric utilities at 70 test sites (RP1095). Twelve significant galloping events were observed during the past season, including some from parallel studies being made by Ontario Hydro and utilities in five European countries. In the United States, galloping reported as far south as the Gulf Coast states caused extensive tower damage and power outages.

While data are still insufficient to make firm conclusions about the level of control provided by detuning pendulums furnished by EPRI, there is sufficient evidence to suggest that detuning devices do reduce the magnitude of galloping. For example, studies on single conductor lines that have span lengths and tensions conducive to galloping show they are about 15 times more likely to experience flashovers caused by galloping than spans that have been detuned with the EPRI detuning pendulum. More data will be required before conclusions can be drawn as to how much control is possible for particular sizes and spans of both single and bundled conductors.

Utility assistance in obtaining data is very important to the success of this project, and continued active utility participation will help provide a timely solution to the problem of conductor galloping. *Project Manager: Phillip Landers*

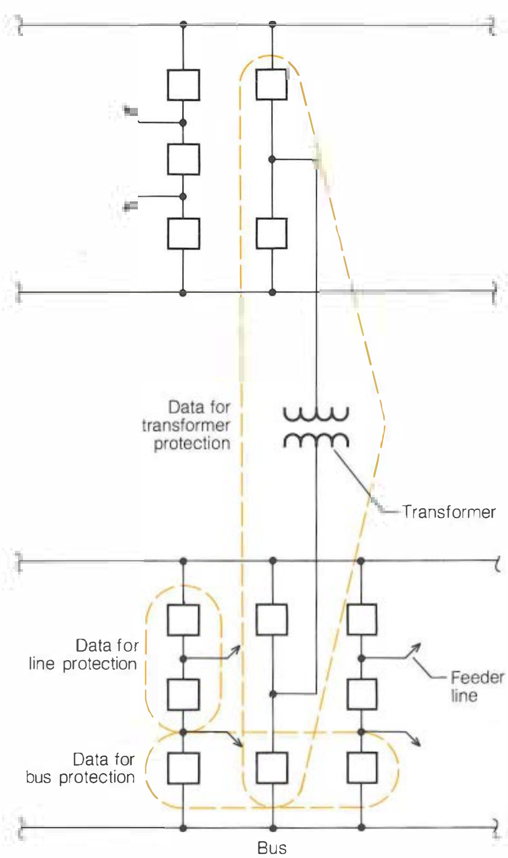
## TRANSMISSION SUBSTATIONS

### Substation control and protection systems

EPRI is sponsoring a project for the development of a new substation control and protection system (RP1359). The goal is to achieve cost reductions and improved system performance by means of a distributed, microprocessor-based system. The microprocessor is a small, relatively low-cost component that could lead to a modular and therefore an expandable and easily maintained system. The system must perform a number of normal data acquisition, control, and protective functions.

- Protective functions: transmission line protection, transformer differential protection, and bus differential protection
- Automatic control functions: breaker failure protection, breaker reclosing, synchrocheck, local load shedding, and local voltage and VAR control
- Man-machine interface: control and indication functions, alarm function, and supervisory control interface
- Other functions: communication system monitoring, transformer load monitoring, line load monitoring, fault location estimation, revenue metering, and logging and fault recording

Figure 4 Data collection zones for protection functions in a typical utility substation.




The main technical challenge is to develop a system architecture that provides the best balance between cost and performance. Not unexpectedly, the topology of the substation poses a major problem to the system architects. The problem lies in the interface between the data acquisition system and the processors. As seen in Figure 4, some functions require data with a bay orientation; other functions are bus-oriented, and still others bridge different switchyards. At the same time, many of the functions share data points. For a minimum-cost system, the redundancy of the data acquisition system must be minimized without sacrificing reliability or security.

Most utilities use a fully redundant protective relay system, and some redundancy in the data acquisition system is therefore unavoidable. Each primary protective relay processor must have direct access at least to all its data and control points. The processors can then perform their functions in a stand-alone operating mode without the need for any ties to other subsystems in operation. A data highway will tie all the relay processors together. Other control and monitoring subsystems, such as an operator interface, data-logging devices, or a supervisory remote terminal unit, will also be connected to the highway.

The major responsibility for system development rests with Westinghouse Electric Corp. (RP1359-1). General Electric Co. will develop one of the system's line protection relay modules (RP1359-5). Ohio University researchers have completed a study of the sampling and computation aspects of a revenue-metering function (RP1359-3), and Public Service Electric and Gas Co. of New Jersey will be the host utility for the demonstration. A special project, evaluation of the electromagnetic interference in substations, is being handled by Texas A&M University (RP1359-2). This study is nearing completion.

The project is expected to produce a prototype system by 1983 that is suitable for commercial production. The prototype will be installed in an operating 500/230-kV substation, where it will be operated for up to five years to gain long-term experience. *Project Manager: Stig Nilsson*

### Gas density monitor

As interest in and use of $SF_6$-insulated substation equipment at transmission voltages grow, research to improve the reliability and cost-effectiveness of this technology becomes increasingly important. One approach is to develop a gas density monitor for use with such systems. As the insulation level of this equipment is directly related to the density of gas, measurement of the gas density plays an important role in the overall monitoring scheme for any satisfactory operation.

Thus far, gas-insulated equipment designs have used pressure-sensing techniques to monitor the adequacy of the gas within a system. This pressure reading is converted to a gas density indication through correlation with a separate temperature measurement. For control and relaying functions, expensive, temperature-compensated pressure limit switches are employed to trip an alarm when the density drops to an unsafe level. The development of a simple gas density monitor would simplify the operating procedures and eliminate the conversion charts now required to read the density of the gas. Further, because the monitor would improve measurement accuracy, minor density changes could readily be detected, thereby permitting early corrective action.

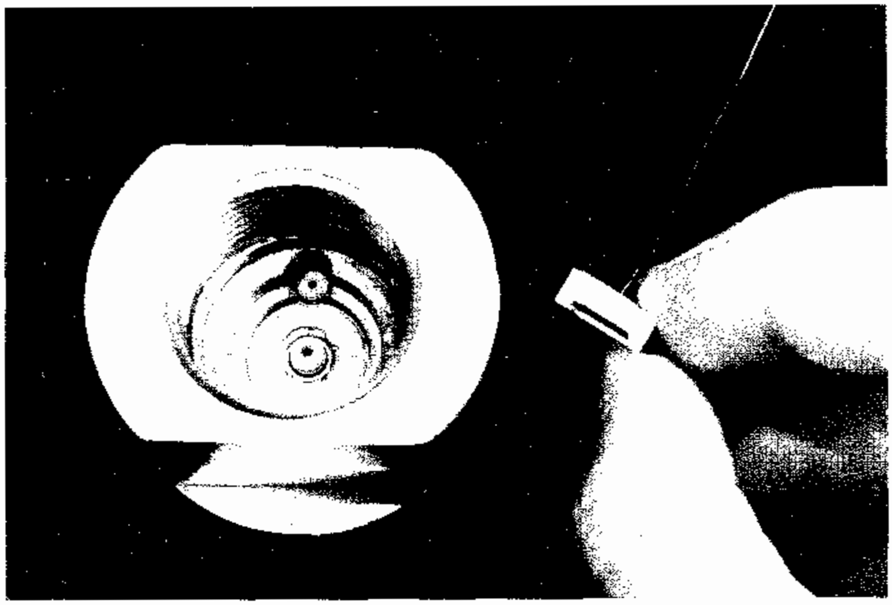
The concept of gas density measurement relies on the linear relationship between the gas density and the saturation ion current resulting from alpha particle bombardment; this principle is similar to that of most domestic smoke detectors now sold in the United States. In fact, the low costs of this approach result largely from the availability of sophisticated integrated-circuit chips developed for smoke detectors.

EPRI has initiated a project with Sigma Research, Inc., to develop a gas density monitor based on the alpha ionization principle (RP1768). The work planned includes investigation of the basic phenomena, studies of temperature sensitivity, and the design, testing, and delivery of a prototype.

The progress thus far has led to a sensor design that has a resolution of 0.1 psi (0.69 kPa) with an accuracy of $\pm$0.5 psi (3.4 kPa) over the entire pressure range. This sensor (Figure 5) employs self-contained batteries with a fairly small leakage current (on the order of 100 mA), resulting in a battery life of two to three years. On demand, gas density is displayed on a three-digit LED readout. The sensor can also be equipped with alarms that are preset at the density levels required for relaying purposes.

This research effort is expected to lead to field-usable monitors that can easily be retrofitted to existing gas-insulated equipment; the monitors should be available for commercial use late in 1980. *Project Manager: Vasu Tahiliani*

Figure 5 An alpha ionization chamber (right) is the sensor for detection of faults in gas-insulated buses. It is mounted in a gas-tight casing (left).



### Carrier frequency noise from HVDC converters

As part of a project to investigate carrier frequency noise generated by HVDC converters (*EPRI Journal,* March 1980, p. 45), General Electric has completed digital models of the valves, transformers, filters, shunt banks, and lines in the Arrowhead terminal of Minnesota Power & Light Co.'s Square Butte HVDC system (RP1427). The investigators have used Bonneville Power Authority's electromagnetic transient program to provide a digital counterpart to the analog dc simulator in Schenectady and to test the program's ability to simulate dc systems.

Deenergized impedance and admittance measurements were taken for various station equipment at the Arrowhead terminal. These measurements were made to further the development and verification of station apparatus models to be used in the analysis. Of particular interest were high-frequency-response measurements made on apparatus assembled in the field, since tests of this response could not be made at the factory.

Measurements were taken on the dc side of the HVDC terminal while the line was energized. These indicated that noise from the positive pole and noise from the negative pole are about equal; the amplitude of the noise tends to be inversely proportional to frequency and is independent of weather conditions. Agreement between the digital model and the measured values has been generally good.

More recently, background noise measurements and energized noise measurements have been performed on both the ac and dc sides. By using bushing capacitance dividers for voltage measurement, noise data were obtained on the valve side of both the converter transformer and the smoothing reactor. Such measurements have never been performed before and will be of value for this research project.

In the next step, overall testing and use of analytic procedures will investigate how variations of valve elements and valve group parameters affect noise generation. Sensitivity to parameters in the ac and dc systems will be determined and used to minimize costs in future designs that incorporate reduction of carrier frequency noise interference. *Project Manager: Gilbert Addis*

## ROTATING ELECTRICAL MACHINERY

### Transformer oil pumps

In most large power transformers, insulating oil that fills the transformer is drawn from the transformer tank, passed through a heat exchanger for cooling, and returned to the transformer tank. Forced movement of the oil is accomplished by means of a pump in the oil circuit.

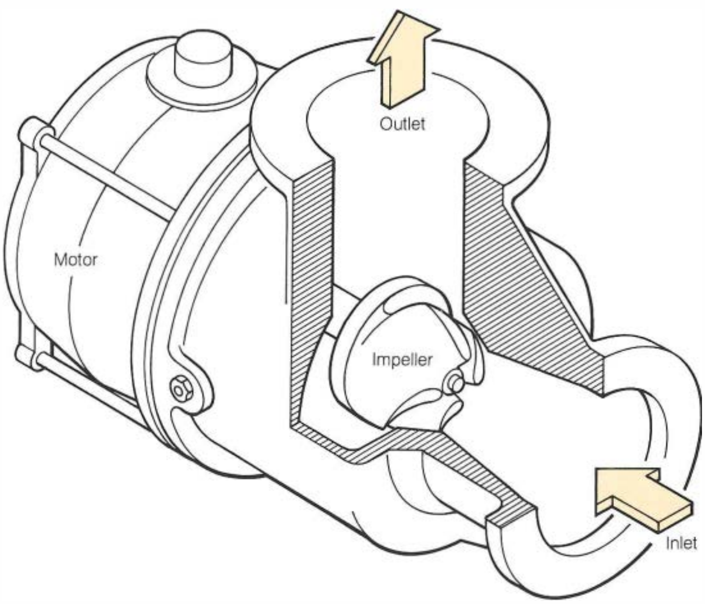
There are two basic pump configurations in common use, both with the motor immersed in the oil. One involves a completely in-line system of motor and impeller, in which the total flow of oil passes through the motor as well as the impeller. In the other, only a small percentage of the total flow passes through the motor (Figure 6). In both cases, the bearings are lubricated and most of the motor losses are removed by the oil.

These oil circulating pumps have failure modes (such as bearing failure and impeller breakage) that can generate metallic debris. This debris is swept into the transformer by the oil discharged from the pump and may settle on the insulation structures of the transformer. A significant number of pumps have failed in recent years, principally involving failure of bearings or impellers, which raises a valid question about the reliability of the system.

The failure of a large power transformer can be very costly, both in terms of its repair and, in some instances, the cost of replacement power. Even without transformer failure, pump failure can result in the transformer's being out of service for weeks while it is thoroughly cleaned and the pump replaced.

Mechanical Technology, Inc., is engaged in a project to design, build, and test an improved transformer oil circulating pump (RP1797). Such a pump must be able to perform its required function satisfactorily without the risk of contaminating the transformer in the event of a pump or pump drive failure. A further requirement of the project is that the concept developed be suitable for application across the full range of ratings required; it should also be suitable, with reasonable design modification, for application to transformers of any manufacture. Retrofit capability is an additional project objective. *Project Manager: J C. White*

Figure 6 Oil pump typical of those now used in transformers. Because pump failure can result in contaminated oil, a project is under way to design, build, and test a pump that will not contaminate the oil on failure.




## DISTRIBUTION

### Anomalous transformer failure

Many utilities have documentation to show that distribution transformers fail at a higher rate during lightning storms than during clear weather. At first thought, this condition might be expected because lightning activity imposes high surge voltages on exposed power systems; however, surge arresters are designed specifically to protect transformers from such high-voltage surges. The documentation seems to call into question whether surge arresters are being properly applied, whether they operate as specified, and even whether the principles of surge protection are valid. Investigations by various utilities have confirmed that the surge arresters connected to failed transformers performed satisfactorily and that the transformers should not have failed.

It is estimated that replacement transformers for such anomalous failures cost utilities $10 million annually. This does not include the labor costs incurred during replacement (frequently performed at overtime rates under emergency conditions) or the cost of customer service interruption. In March of this year EPRI initiated a project with General Electric to find out why anomalous failures occur and how they can be prevented (RP1532).

It is known that the waveshapes adopted by the utility industry for equipment test purposes do not comprehensively match the waveshapes of natural lightning currents and the voltages produced by those currents. This difference is unavoidable because the statistical distribution of natural waveshapes is not known. It will be years before a valid data base of waveshapes can be developed.

Waves of various shapes can be produced in the laboratory with relative ease. By analytic and experimental means, the waveshapes that are most harmful to full-scale core and coil assemblies of the commonly used constructions can be determined. Using waveshapes selected in this manner, General Electric researchers will determine the protective characteristics of surge arresters and assess and test the degree of coordination between fuses and surge arresters.

It is known that age and loading history degrade the ability of transformer insulation to withstand surges; tests using the waveshapes found to be most harmful will also be performed on aged transformers under load to determine more precisely the relationship of aging to this degradation. There is some evidence that secondary windings are also involved in anomalous failures; another important phase of the project will therefore investigate surge voltages in the secondary windings. Further, the production and effects of corona in the windings will be studied.

To ensure the applicability of the project findings to the real-world problem, full-scale samples of the commonly used types of transformers will be employed whenever possible. Full-scale outdoor test facilities will be used to introduce test voltages into both primary and secondary windings. Complete transformer–surge arrester systems will be used to demonstrate failure modes and, if possible, the effectiveness of the steps that can be taken to eliminate the failures. Although most of the research will be performed with equipment suitable for nominal 13-kV systems, the results will be convertible to systems of other voltages by digital computer modeling techniques.

This project is now in its eighth month and will be completed by April 1982. Several utilities are participating by tearing down transformers that failed during storms and reporting their failure modes. Sample transformers for transient analysis and insulation impulse studies have been built and are under test. *Project Manager: Herbert Songster*

**Underground cable installation**

Electric utilities install more than 100 million feet of underground cable annually. A large portion of this cable is directly buried in new residential subdivisions and commercial developments by conventional cut-and-cover installation methods. Although the trenching method is effective, it is also slow and expensive.

The annual cost of installing buried cable is approximately $500 million. Any significant improvement in installation methods would effect a large saving in utility construction costs. One such improvement is development of an improved cable plow with greater versatility than those now available. Most utilities agree that cable plowing should be the least costly method of installing cables; however, existing cable plows do not cover the full range of utility requirements.

Oretek Laboratory, Inc., has started a three-year project to develop and demonstrate a compact, highly maneuverable cable plow capable of simultaneously installing multiple cable systems at various depths and separations (RP1518). The plowing system will incorporate several innovative features that together will greatly advance the state of the art; the system will be capable of operating in subdivision developments, as well as in rural areas, and in all types of soils. *Project Manager: Thomas J. Kendrew*

**Composite wood utility poles**

Forest resources that supply wood poles for the utility industry must also supply the timber, lumber, pilings, and wood pulp for many other industrial and commercial uses. These resource demands threaten the survival of trees suitable for wood poles, especially those over 50 ft (15 m) long; as a result, the price of poles is high and the selection limited.

The primary objective of a research effort with the Institute of Wood Research at Michigan Technological University is to demonstrate the feasibility of manufacturing distribution and transmission poles from composite wood material (CWM). This material can be made from species such as red alder, balsam fir, and aspen—species that are in adequate supply and have more stable costs (RP796).

The boards used to construct CWM poles measure 1 × 18 in (2.5 × 46 cm) and are manufactured in various lengths by compressing wood flakes in a heated press. The flakes are prepared from a roundwood flaker, classified for size uniformity, and sprayed with a preservative and thermosetting adhesive. They are then aligned (with wood fibers parallel) on a conveyer that feeds the press. A variety of section shapes were studied to arrive at a pole design that could be made with the composite wood boards. Both efficiency and esthetics dictated an octagonal shape. The cross section of the pole is built up from laminations of the CWM; the number of laminations depends on the stress on the wood at the section under consideration. Thus, interface adhesives are required both to glue the board surfaces together and to glue the edges to form the octagonal shape. ANSI pole specification strengths were used as the design criteria for the strengths to be achieved in the composite wood pole designs.

Extensive testing was performed throughout the project. Adhesives were selected after severe strength and durability testing, including exposure to ultraviolet light, boil-and-dry cycling, and stake test exposure (to measure decay attack). Basic strength tests were performed on the composite wood boards, both before and after the severe exposures. Modulus of rupture before exposures was approximately 15,000 psi (103 MPa), and after the boil-and-dry cycling, approximately 12,000 psi (83 MPa). The 20% loss is approximately the same as for solid wood in similar tests. Flame tunnel tests on the CWM indicate that it burns less readily than solid wood under similar exposure. Under leakage current stress, the CWM samples scarred less than a standard wood cross-arm under identical stress. Final full-length pole tests to develop data on load versus deflection up to ultimate failure are in progress for final design verification.

A number of full-size pole samples will be produced by the end of the project. Arrangements for field trials and evaluation will give a number of utilities an opportunity to determine the acceptability of this substitute pole in service. Attention will be directed to all operations normally involved in placing poles in service, including handling in and out of the pole yard, framing the pole, erecting it, climbing it, and making attachments.

If field evaluations indicate good utility acceptance, a number of benefits are envisioned in addition to ensuring an adequate supply of poles at a reasonable cost. As a manufactured product, the physical properties of the composite wood pole are more uniform than those of solid poles. There are no knots, shakes, ring separation, or undetected decay pockets as points of reduced strength. As all wood fibers receive preservative treatment during pole manufacture, there is no problem of preservative penetration. Pole checking can not occur because the flakes are dried and then sealed by the adhesive. The moisture-absorbing property of the composite wood is half that of natural wood because of its high density after compression.

Commercialization of this concept will require both acceptance by the utilities and the development of production facilities by a reputable manufacturer. *Project Manager: Robert Tackaberry*

# R&D Status Report
# ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

## NEW DIRECTIONS FOR THE SUPPLY PROGRAM

*The Supply Program of EPRI's Energy Analysis Department is dedicated to providing analyses and analytic tools for the utility industry and for EPRI R&D planners. This year, in response to the changing needs of utility planners, the program's research efforts are being reorganized to address supply issues in a broader context. Previously the program concentrated on developing forecasts and analyses of basic fuel resources, which were used primarily by EPRI R&D planners. Now supply is being considered in the context of the utility as a business that converts basic inputs (fuel, capital, land) into a unique and convenient form of energy. Forecasting the availability and price of basic resource inputs will continue to be an important aspect of the program's research, but the conversion of those resources into electricity and the survival of utilities in an environment of uncertainty and constraint will receive greater emphasis.*

### Program goals

The goal of the Supply Program is to provide methods, forecasts, and information for analyzing the electric utility as a regulated business entity that uses fuel, capital, and other economic resources to meet fundamental energy requirements in an uncertain and constrained environment. Products of program research include analytic tools specially designed for utilities, analyses of fuel and other resources, and forecasts of energy supply from electricity and other sources. Specifically, the Supply Program seeks to develop the following.

- Utility planning models capable of integrating supply, load management, and rate options

- Integrated generation expansion–corporate planning models that consider financial and regulatory constraints as well as engineering-economic factors

- Analytic methods for examining the cost-effectiveness for utilities of (1) vertically integrating resource supply activities and (2) providing integrated energy services

- Analytic methods for evaluating the effect of institutional and regulatory constraints on electricity supply

- Analyses of how constraints on such resources as water, capital, land, labor, equipment, and materials affect the utility as a supplier of electricity and as a business entity

- A fuel supply analysis system to provide utility and EPRI planners with a continually updated assessment of basic fuel inputs (including supplies from new technologies) from geologic resource base to ultimate user

The Supply Program's new five-year plan recognizes that traditional planning methods are no longer adequate to reflect the realities of the environment in which utilities must operate. The uncertainties and constraints of this environment may preclude the implementation of desirable capital investment programs. These realities must be effectively communicated to regulators and other external policy makers if the potential contribution of EPRI's technological research into solutions for the national energy dilemma is to be realized. The development and transfer to the industry of analytic tools that integrate engineering, economic, and regulatory factors will enable utility managers to respond more effectively to the complex responsibilities placed on them.

Utilities must consider alternatives for surviving in this constrained environment. One is to vertically integrate resource subsidiaries. Another is to supply integrated energy services by becoming involved in such end-use technologies as cogeneration, insulation, and solar heating and cooling. The development of analytic methods for evaluating the economic and institutional aspects of diversification options, as well as the impacts of such evolving technologies as fuel cells and decentralized generation, will help utilities choose between alternatives.

Forecasts of energy supply will continue to be of direct interest to utility and EPRI planners. It is essential to know the projected level of generating capacity in order to determine when new technologies will be needed. Further, capacity requirements are functions not only of economic and demographic factors but also of the price and availability of electricity and other forms of energy. The Supply Program provides estimates of these values for use by the Demand and Conservation Program in preparing demand forecasts.

### Program organization

To reflect the increased emphasis on the analytic requirements of the utility as a business entity, the Supply Program has been reorganized into four functional areas: electricity supply, utility planning methods, fuel supply analysis, and economic resources.

For each subprogram a formal plan will be prepared that defines research objectives, the level of effort required, and the form and content of the analytic products to be provided. In each case the planning process will focus on identifying the needs of utility and EPRI planners. The program's five-year plan will integrate these subprogram plans and determine priorities in order to meet the identified needs of the utility industry to the extent permitted by budget constraints. Particular attention will be given to determining exactly what level of effort is necessary to meet the industry's requirements for forecasts of basic fuel resources, which currently constitute a major portion of the program's research.

*Electricity Supply* This subprogram will focus on the electricity supplied by utilities—characterized by price, quantity, and reliability—and will attempt to determine how such factors as unit mix, size, and obsolescence affect those characteristics. One major objective is to develop generic generation expansion models that take into account inflation, financing, load management, and the planning of generation and system interties. Such models will be tailored to the needs of corporate planners and will not have as much detail on electrical systems as models used by system planners.

*Utility Planning Methods* This subprogram will focus on the analytic tools needed by utilities in responding to constraints and uncertainties about fuel, capital, and other economic resources and in adapting to changes in the business, financial, and regulatory environment. The subprogram will use information and analyses from other subprograms to develop analytic methods for evaluating the economic and institutional aspects of alternatives available to the utility as a corporate entity. Specifically, analytic capabilities will be developed to evaluate:

- Vertical integration of resource inputs, such as fuel subsidiaries and fuel transportation facilities
- Supply of integrated energy services by utilities through involvement in end-use technologies (e.g., insulation, solar heating and cooling, and cogeneration)
- Allocation of investment funds between end-use and supply facilities
- Institutional and regulatory constraints on electricity supply, including inflation accounting, construction work in progress, and Public Utility Regulatory Policies Act (PURPA) regulations
- Variable-reliability pricing, including pricing by level of service and spot pricing in connection with computerized load control
- Business impacts of new technologies, such as fuel cells and decentralized generation

*Fuel Supply Analysis* This subprogram is responsible for the analysis and forecasting of fuel supply from resource discovery through production and delivery to the ultimate consumer. Its research will seek to clarify the physical, economic, environmental, social, regulatory, and political factors that govern the availability and price of fuels. Also covered are certain nonfuel energy sources, such as solar and geothermal. Efforts by the utility planning methods subprogram to develop tools and procedures to assist utilities in fuel procurement will draw heavily on the work of this subprogram.

*Economic Resources* The primary objective of this subprogram is to provide forecasts and analyses of basic nonfuel resources, including water, capital, land, labor, equipment, and materials. A related objective is to evaluate the impact of resource constraints on the production of energy and the operation of the utility as a corporate entity. In the past the focus of such research has been water availability and its effects on energy production. New areas of research include the availability of capital and the estimation of lead times for power plant siting. *Program Manager: Eugene Oatman*

## TECHNOLOGY RISK ASSESSMENT

*Newspapers and scientific journals have recently cited estimates of the occupational and public health risks of different energy technologies. These estimates have generated considerable criticism, directed mainly at their descriptions of how nonconventional plants operate and at numerical inaccuracies. In view of this criticism, EPRI has started a research project (RP1772) to assess the public and occupational health risks of eight technologies for producing electricity: coal, nuclear, oil, gas, solar central receiver, solar photovoltaics, wind, and biomass. Risks will be calculated for commonplace and catastrophic hazards, taking into account uncertainties in the data and models. The project is limited to health risks; it will not evaluate ecological and other indirect health risks (e.g., the greenhouse effect, dependency on foreign suppliers).*

Most energy-related activities affect occupational and public health to some degree. Technology risk assessment is the study of such impacts. It takes into account public and occupational deaths, injuries, and illnesses that result from all the activities associated with a technology—the fuel and material cycles, transportation, construction, power generation, and waste disposal. Recently, controversies have developed both in the press and in scientific journals over the accuracy of risk assessments. These disputes forcefully indicate that research is needed to determine the net costs and benefits of producing power from conventional (e.g., coal and nuclear) and nonconventional (e.g., solar photovoltaics and wind) sources.

The controversy centers on a recent report concluding that the health risks of nonconventional technologies are greater than those of nuclear power (*1*). On the basis of a partial reanalysis of the work, others hold that the study overestimates the risks of nonconventional technologies and these technologies are, in fact, less hazardous than nuclear power (*2*). An initial EPRI review of these risk assessments suggests that while important technological issues were addressed in the original report, conceptual and numerical inaccuracies must still be resolved. Toward that end, a methodology for risk assessment is being developed for use in the RP1772 analyses.

### Risk modeling

Risk is calculated as the product of the frequency of an event and the magnitude of the event's adverse consequences. This approach can be used to estimate the occupational and public health risks of common and catastrophic events. Because occupational risks are assumed to be voluntarily accepted by those at risk, they have not traditionally been grouped with public health risks. Similarly, catastrophic and commonplace risks are not normally combined because of the different public perception of catastrophic events. These risks will be kept separate in the analyses performed under RP1772.

The project will take a cradle-to-grave approach to risk assessment, that is, it will calculate occupational and public health risks for all stages of energy production: the extraction of minerals and fuels; their transportation and processing into final products; power plant construction; the generation, transmission, and distribution of electric energy; and waste disposal. The assessment of risk thus depends on an accurate characterization of the activities and energy cycles associated with each technology, as well as on knowledge of commonplace and catastrophic events and their frequency.

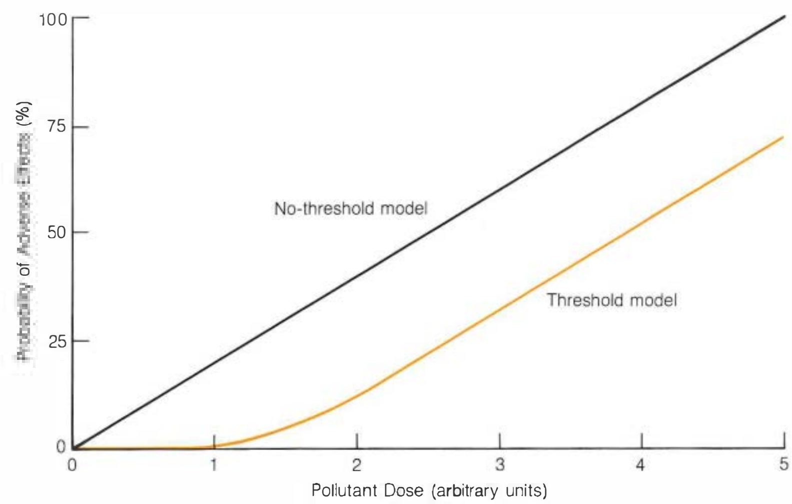
A cradle-to-grave risk assessment of coal technology, for example, would include the occupational deaths resulting from the mining of subbituminous coal. The risk is calculated as the number of deaths per million tons of coal mined for a specific time period. Determining one part of that risk, the occupational deaths due to chronic exposure to a toxicant during mining operations, requires information on the dose (the amount of toxicant ingested or inhaled) and the biologically adverse response (estimates of excess deaths). Mathematical and statistical methods are used to model the relationship between dose and response to yield the incidence of the adverse effect. Demographic data are then used to estimate the total number of deaths caused by chronic exposure.

In characterizing utility operations, a risk assessment must take into account the possible need for backup power or energy storage for nonconventional power plants; this need depends on how a utility dispatches a nonconventional plant. Other factors affecting risk calculations are a plant's lifetime, which may differ for conventional and nonconventional power plants, and whether the assessment is made for an average plant or a marginal plant.

The choice of units of risk to be used depends on the purpose of the assessment. For example, if the purpose is to determine the public and occupational risks of energy production nationwide, then a measure such as person-days lost per unit of energy produced may be appropriate. If the assessment is being performed for labor unions, person-days lost per employee may be a more appropriate measure.

The current EPRI risk research relies on a systems analysis approach and on an input-output model that has been modified to include risk information. The input-output model considers both direct and indirect requirements of a technology in terms of energy, materials, fuels, and activities. Because the data used in the model are not detailed enough for technology risk assessment, the model is coupled to various engineering estimates. Still, the model and data bases can only approximate real-world conditions. Thus it is important that uncertainties be included in a risk analysis. RP1772 will use nonparametric methods, Monte Carlo simulation, and similar techniques for this purpose.

Figure 1 Dose-response models for predicting the health risks presented by inhalation or ingestion of toxic substances. The no-threshold model predicts a direct linear relationship between dose and effect. The threshold model holds that effects are negligible for doses below a certain threshold—in this case, a dose value of 1.




### Pollutants and dose-response models

The processes and activities associated with electric power production result in the release of various solid, liquid, and gaseous pollutants, which are transported in the air, in water, and through the ground. These pollutants may be inhaled or ingested by man. Mathematical models based on experimental results and theoretical calculations are used to predict the behavior of pollutants and their fate.

The relationship between the amount of a pollutant inhaled or ingested and its toxic effects is given by a dose-response model. Figure 1 illustrates two such models: the no-threshold model and the threshold model. At low doses, the responses predicted by the threshold model may differ by orders of magnitude from the responses predicted by the no-threshold model. The most appropriate mathematical form for a dose-response model to be used in risk assessment is not obvious because experimental data on response are not normally available for low doses. The problem of data availability is especially troublesome when an adverse effect has a long latency period, takes the form of subtle physiological changes, or is not statistically distinguishable from the effects of exposure to background levels. Dose-response models, which normally propose a mechanism of biological damage, are calibrated by data from in vitro tests, animal studies, or human epidemiological studies. RP1772 will consider the usefulness of such data for estimating the dose-response relationship.

### Application of results

Most, if not all, human activities are risky. The generation of electric power is no exception, whether it involves renewable or nonrenewable sources of energy. Under RP1772 EPRI is seeking to identify the possible health risks associated with various power generation technologies, as well as uncertainties in the measures of those risks. It is hoped that this work will resolve some of the differences between current risk estimates. Project results should be useful to the utility industry in planning the development of new technologies, in developing technologies that minimize risks, and in compiling risk information for specific components of various types of power plants.

The information provided through risk assessment must be supplemented by information on the economic and engineering feasibility of technological options for generating electric power and controlling emissions. These areas are outside the scope of RP1772 and will be considered in future research projects. *Project Manager: Paolo F. Ricci*

### References

1. H. Inhaber. *Risk of Energy Production.* Ottawa, Canada: Atomic Energy Control Board, November 1978. AECB 1119/Rev. 2, 3rd ed.

2. *Risk of Renewable Energy Sources: A Critique of the Inhaber Report.* Berkeley, Calif.: Energy and Resources Group, University of California, June 1979. ENG 79-3.

# R&D Status Report
# NUCLEAR POWER DIVISION

Milton Levenson, Director

## BWR RADIATION CONTROL

*Control of radiation fields in BWRs requires a multifaceted approach. Plant designers, chemists, and operators all play a role in a successful program. Radiation control involves minimization of corrosion-product input to the reactor, control of cobalt release and transport, and decontamination of system components. The research in this area includes laboratory studies of corrosion-product solubility; deposition studies; measurements of piping, fuel, and component contamination; and tests conducted in operating nuclear power plants.*

Radiation exposure of nuclear plant workers in this country continues to increase. According to an analysis of recent U.S. experience, BWR radiation exposure is increasing by approximately 50 rem per plant per year. Many factors contribute to plant exposures. This makes it extremely difficult to evaluate the contribution of any single element. However, some conclusions can be drawn by studying plant exposure experience. Of particular interest are plant capacity and years of operation. Plant radiation exposure does not appear to be directly proportional to unit capacity (i.e., larger plants do not produce proportionally higher occupational exposures). An examination of the operating histories of older units reveals that annual plant exposures increase during a plant's early life and peak at 3–5 years. In the next few years, there is a gradual decrease to a lower plateau. (It should be noted that only a few plants are old enough to be in this stage.) It is expected that exposures will return to a higher level later in a plant's life, when equipment failures become more frequent and radiation fields reach higher equilibrium values. It is this possibility that has given impetus to EPRI's research into radiation control techniques.

The principal effort to identify BWR radiation control techniques is being conducted by General Electric Co. (RP819). An essential element of this project has been the monitoring of radiation fields at representative operating BWR plants. Through this monitoring, considerable insight has been gained into the relationship between design features and radiation field buildup. The data gathered have provided a means of evaluating the effects of forward-pumped heater drains, condensate demineralizer designs, reactor demineralizer capacity, and feedwater chemistry control programs.

Supplementing this monitoring program are deposition studies being performed on a test loop at the Hatch-2 reactor of Georgia Power Co. Specific topics of investigation are the characteristics of corrosion-product deposits, the effect of operational transients, the impact of high-temperature filtration, and the mechanisms of radioisotope transport.

### Radiation buildup mechanisms

Plant monitoring has established cobalt-60 as the major contributor to BWR radiation fields. This isotope is produced by activation of natural cobalt, which is released to the coolant through wear and corrosion of alloys within the system. Cobalt is the major material in wear-resistant alloys and also is present as a low-level impurity in numerous iron-nickel alloys. Efforts are under way to identify the significant sources of cobalt in BWR materials (RP1331 and RP1784). Where possible, these will be eliminated by using an alternative material. Because cobalt will remain in the system as a low-level impurity, cobalt control techniques are also being developed.

It is believed that iron corrosion products play a fundamental role in cobalt activation and transport. Iron is released from corroding surfaces and is transported through the feedwater system to the reactor. When deposited on the surfaces of the reactor fuel assemblies, this material provides residence sites for cobalt. It is during this residence period that natural cobalt is activated to cobalt-60. The quantity and species of iron present in the feedwater determine the character of the deposit. Tightly adherent deposits are formed when the feedwater iron is maintained at very low levels. These deposits appear to effectively immobilize the cobalt, preventing it from migrating to out-of-core surfaces.

This theory is supported by data from the Oskarshamn plant in Sweden and the Tsuruga and Shimane plants in Japan, which maintain total iron input to the reactors at less than 1 ppb and have the lowest BWR radiation fields in the world. Iron concentrations in this range can only be achieved with an optimally designed feedwater system that is operated with meticulous attention to water quality.

It is obvious that effective operation of the condensate demineralizer system is crucial in minimizing the feedwater's iron content; equally important is the control of dissolved oxygen in the feedwater. Also, the procedures followed in plant startup, shutdown, and layup help determine iron input to the reactor. All these factors must be considered in an integrated effort to control iron-cobalt radiation buildup.

Contamination of out-of-core corrosion deposits takes two distinct forms. In one, the suspended radioactive material can deposit on the metal surface as a loosely adherent deposit. In the other, radioactive cobalt present in the water can become incorporated into the corrosion film as it forms. This second mechanism is the controlling factor for out-of-core radiation buildup.

In the ultrapure water chemistry of the BWR, the corrosion process is directly related to the level of dissolved impurities. The presence of dissolved impurities in the unbuffered BWR coolant increases the corrosion of the primary system. Normally, the impurities encountered are sulfates and chlorides resulting from condenser leaks and organic acids from resin intrusion and degradation. The presence of these contaminants both increases the conductivity of the water and, in the unbuffered coolant, results in an increase in corrosion rates.

A recent analysis by General Electric indicates a direct correlation between out-of-core radiation buildup and increased feedwater and reactor water conductivities (i.e., increased levels of impurities). This has important implications for the operation of the condensate and reactor water demineralizer systems. Since higher levels of impurities in these waters promote corrosion and out-of-core contamination, off-standard chemistry conditions must be immediately corrected. The out-of-core contamination resulting from frequent or prolonged excursions can generally be removed only by radioactive decay or by the slow process of diffusion through the deposit.

### Decontamination

In the past few years considerable experience has been gained in decontaminating BWR systems. Monitoring programs have been initiated at two decontamination projects, one at Peach Bottom-2 (operated by Philadelphia Electric Co.) and the other at Vermont Yankee (operated by Vermont Yankee Nuclear Power Corp.). These projects involved decontamination of the heat exchangers and interconnecting piping in the reactor cleanup system. Early results indicated the decontamination treatment to be very effective in reducing contamination and associate radiation fields; but when the systems were returned to service, their high-temperature surfaces were quickly recontaminated. In some cases, radiation fields exceeded their original predecontamination levels. Unless effectively passivated, the decontaminated surfaces initially experience an accelerated corrosion rate. It is during this period that radioactivity in the coolant is incorporated into the corrosion film.

The low-temperature surfaces did not rapidly become recontaminated. When high radiation levels were detected in these sections, they were believed to result from loosely adherent deposits on the low-flow surfaces. Considerable time is required for such deposits to become reestablished. At lower temperatures, corrosion proceeds much more slowly and the incorporation of coolant activity is less pronounced.

Decontamination is a proven technique for BWR component radiation reduction. It can be used to reduce radiation fields for maintenance and inspection activities. Until effective passivation techniques are available, however, rapid recontamination of high-temperature surfaces should be anticipated.

### Radiation control demonstration

Controlling radiation fields in a BWR involves a comprehensive program of applied power plant chemistry. Such a program is based on the following elements.

- Assessment of existing radiation conditions and operating practices
- Minimization of iron contamination in the feedwater
- Control of dissolved oxygen in the feedwater
- Optimization of demineralizer system operations
- Establishment of favorable startup, shutdown, and layup practices
- Use of system decontamination techniques

The design of some BWRs limits radiation control, and these plants will require modification. For example, some plants may require oxygen control equipment or purification of forward-pumped heater drains in order for the desired chemical conditions to be attained.

In the near future EPRI will initiate a BWR radiation control demonstration (RP1934). In this project an integrated program of radiation control will be implemented at an operating BWR and its effectiveness assessed over a four-year period. In addition, investigations of activity transport mechanisms in BWRs will continue. *Project Manager: Michael D. Naughton*

## CALIBRATION OF ACOUSTIC EMISSION SENSORS

*The acoustic emission (AE) technique has great potential for determining and monitoring structural integrity. AE signals contain potentially useful information about the location and identity of defects and about the criticality of these defects in a structure under load. However, current signal reception methods do not preserve all the available information, and signal-processing techniques often fail to extract the remaining information unambiguously. The difficulty lies both in the inherent complexity of the mechanisms that generate transient stress waves and in the lack of understanding of the transient wave propagation details and the physics of the sensor's mechanical-to-electrical conversion process.*

An AE sensor, usually a transducer, converts a mechanical disturbance (stress wave) to an electric signal. The conversion process can be formulated as a functional relationship between the sensor's input stimuli—specifically the traction (force per unit area) and particle velocity—and the sensor's electric output signal. Unfortunately, because individual transducers have characteristics of their own, different sensors will not necessarily produce the same output signal for a common input. This variation in sensor characteristics makes it difficult to tell which components of the output signal really represent the disturbance input and which represent distortions introduced by the sensor during the conversion process.

The problem has been addressed as part of a joint project with the National Bureau of Standards (NBS). To clarify the sensor conversion process an apparatus was developed that can calibrate individual AE transducers to a standard transducer of known characteristics (RP608).

### Theoretical approach

A transfer function model with a number of simplifying assumptions was used as the basis for the calibration technique. The calibration apparatus was constructed to realize this theoretical model in the laboratory and to test its underlying assumptions. The apparatus design was based on the model's premise that the surface motion resulting from a step-function force event generated on the surface of a large elastic block is exactly calculable by elastic theory up to the time of arrival of reflection from boundaries.

The basic setup (Figure 1) involves placement of two transducers on the surface of a large steel block—one transducer, with known characteristics, is used as a standard for comparison with the other, with unknown characteristics. The transducers are placed equidistant from a force generator, which produces an acoustic stimulus on the block surface. Acoustic energy, traveling in hemispherical waves through the block, is picked up by both the standard and the unknown transducer. The difference in the outputs of the sensors represents the deviation of the unknown transducer from the standard; this difference can be represented as a mathematical expression that will define the unknown's characteristics with respect to the standard in all future applications.

### Calibration apparatus

Each component of the apparatus was designed to operate within the constraints of the theoretical model (Figure 2). The steel block is 90 cm in diameter and 43 cm thick, which allows for 100 $\mu$s of data taking before reflections from the block's boundaries can

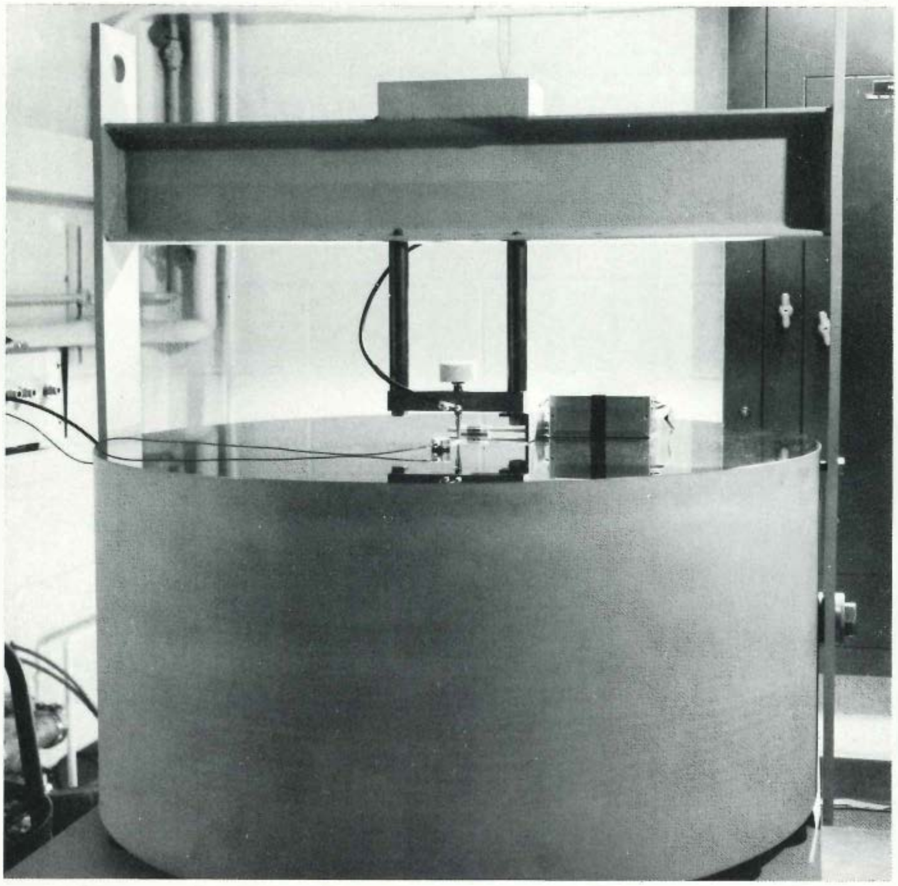


Figure 1 The NBS acoustic emission sensor calibration apparatus. The force generator's needlelike indentor in the center of the highly polished steel block creates an acoustic wave that travels along the block surface to be picked up by the standard transducer (behind the indentor) and the unknown transducer (in front of the indentor). The box at the right is a high-input impedance amplifier for the standard transducer.

interfere; thus, for the first 100 $\mu$s, the block simulates an elastic transfer medium of infinite dimensions. The block surface is finished to an optical polish with a local flatness of 0.1 $\mu$m. This polish is necessary to ensure that a well-defined surface is presented to the transducers and to eliminate questions about the effects of surface roughness on wave propagation.

The force generator consists of a screw device (indentor) that exerts pressure on a small (0.2 mm OD) Pyrex capillary tube resting on the block. When the tip of the indentor crushes the capillary, the total force on, and displacement of, the block surface is released suddenly, creating a step function driving force of the propagating acoustic wave. This function has a well-known time and frequency content and is suited for use with the theoretical model. The force generator contains a sensor of its own, which has been calibrated with dead weights to measure the actual force applied when the Pyrex capillary collapses. Measurement of the sensor's electric output yields force values that can be used in the mathematical transfer function, and the load history is also recorded in a display mode. This display serves as a record of the initial acoustic stimulus and can be used as a reference curve in scaling the magnitudes of response of the transducers being calibrated. Comparisons of output values of the force generator's sensor and the standard transducer have shown good absolute agreement, establishing the validity of the theoretical model's basic assumptions.

The standard transducer is a laboratory simulation of an infinitely long cylinder, the capacitance of which with respect to the flat surface of the block can be exactly calculated. The standard transducer is actually a

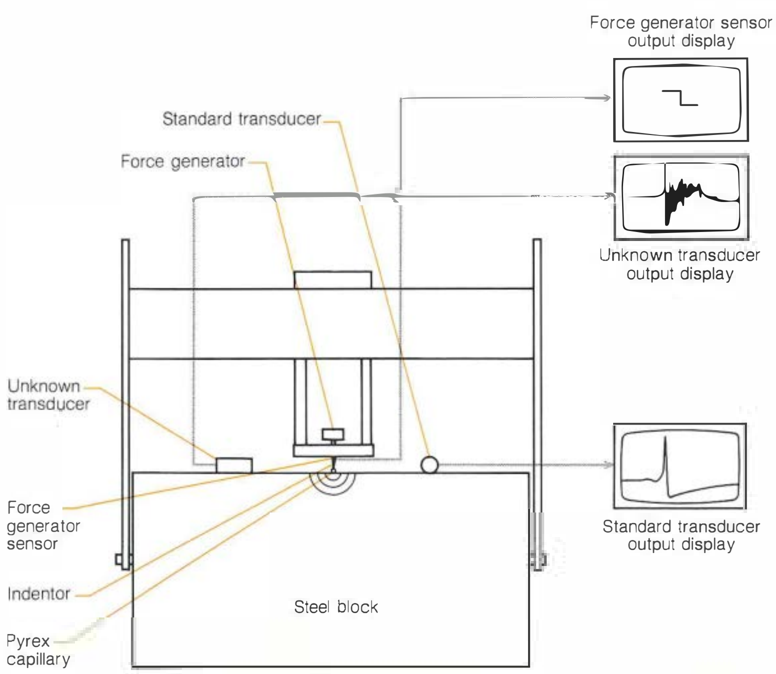



Figure 2 Acoustic energy released by crushing a small Pyrex capillary is translated into electric output signals by the standard and unknown transducers. Differences in the output displays of these transducers represent distortion introduced by the mechanical and electric resonances of the unknown transducer itself. The output display from the force generator sensor gives a record of the force actually applied to the block (note the step-function shape) and can be used to scale the transducer output values.

short brass cylinder with an insulated guard ring on each end. The guard rings eliminate end effects caused by the finite length and allow application of the infinite-cylinder theoretical solution in the electrostatic equations. Use of a circuit similar to that of a condenser microphone allows the gap between the cylinder and the block surface to be measured with a sensitivity of about $10^{-12}$ meters as a function of time. Thus the vertical motion of the block surface can be exactly recorded as the acoustic wave passes the transducer. The standard transducer rests above the block on supports that are sufficiently compliant to prevent distortion of the surface motion. In contrast, the bottom surface of the unknown transducer makes direct contact with the surface, as it would in normal use. The resulting loading effects of the unknown transducer are included in its calibration.

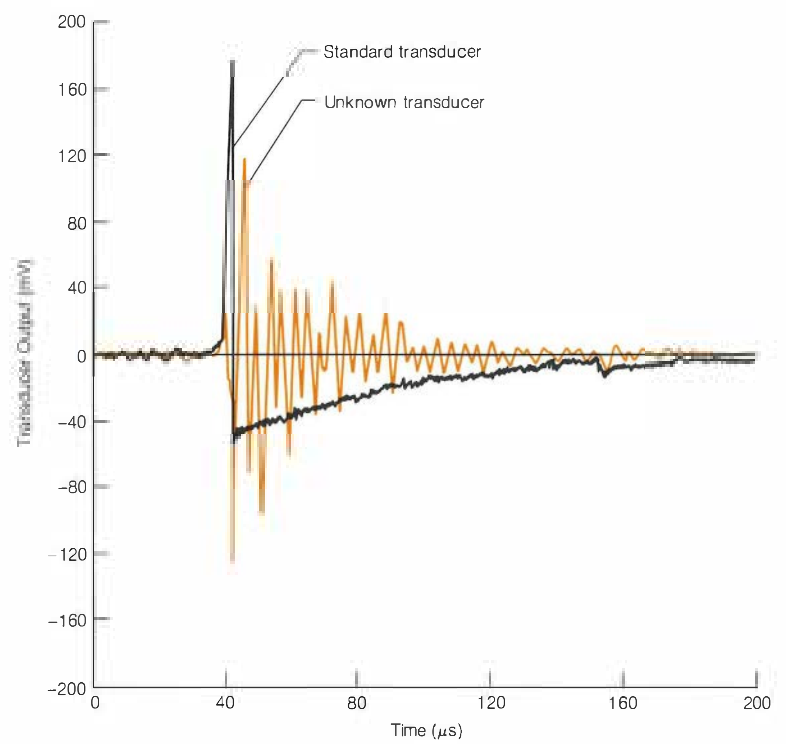
### Transducer output

The surface displacement histories recorded through the standard and unknown transducers are distinct, as shown by superimposition of their output displays (Figure 3). This difference arises from differences in the response characteristics of the two. The unknown transducer, based on the piezoelectric effect, is subject to mechanical and electrical resonances; this makes it difficult to infer the actual block surface motion from the output signal. The standard transducer, based on the capacitance principle, is designed to be immune to these resonances.

The distortions resulting from resonances inherent in the unknown transducer can be removed from its output signal by applying well-known Fourier analysis and deconvolution techniques, by which the output of the unknown transducer is forced to the output curve of the standard transducer. A calibration curve for the unknown unit results from the analysis, and this curve allows the removal of the transducer's unique distortions from its output signal. A field-usable transducer (the unknown), once calibrated in this manner, will generate undistorted measurements of surface motion in all future applications.

The most significant impact of the NBS calibration facility will be greater AE test data reliability and increased validity of interlaboratory data comparisons. Technology transfer from this part of the EPRI–NBS project has been rapid in that several manufacturers of AE sensors have set up, or are in the process of setting up, secondary calibration apparatus, which will allow calibration of production-model transducers at their own facilities, with periodic recalibration of the standard transducers at the NBS facility. *Project Manager: James Quinn*

Figure 3 Transducer responses to a step-function acoustic stimulus. The output curve of the standard transducer retains the key elements of the actual input, but the obvious ringing effect in the unknown transducer's output curve completely camouflages the original step shape. After the unknown's inherent resonances have been characterized mathematically through calibration with the standard, this distortion can be eliminated.



# New Contracts

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP452-3 | Processing of ENDF/ B-V-Based Nuclear Data Libraries for Monte Carlo Applications | 6 months | 42.5 | Mathematical Applications Group, Inc. *O. Ozer* |
| RP1233-6 | CRACIT Code—Benchmark Comparison | 9 months | 27.9 | Pickard, Lowe and Garrick, Inc. *I. Wall* |
| RP1237-3 | Line Spring Fracture Modeling of Nuclear Pipes and Vessels | 1 year | 59.8 | Massachusetts Institute of Technology *D. Norris* |
| RP1276-7 | Preliminary Evaluation of the Potential for Generating Electric Power in Connection With Producing Steam for the Enhanced Recovery of Oil | 5 months | 16.4 | RMR Associates *R. Mauro* |
| RP1415-4 | Thermophotovoltaic Conversion: Radiator Development Program | 6 months | 65.3 | Atlantic Research Corp. *J. Bigger* |
| RP1509-1 | 1-MW (th) Solar-Thermal Conversion, Full-System Experiment | 8 months | 340.4 | Boeing Engineering & Construction *J. Bigger* |
| RP1613-2 | Costs and Benefits of Load Management on the Gulf States Utilities | 3 months | 23.9 | ICF Incorporated *V. Niemeyer* |
| RP1616-11 | Plume Model Validation: ALPHA I Operation and Data Reduction | 8 months | 335.0 | SRI International *G. Hilst* |
| RP1644-1 | Fusion-Fission Hybrid Design Tasks | 13 months | 155.2 | Combustion Engineering, Inc. *N. Amherd* |
| RP1648-4 | Particulate and Water-Content Monitoring System for Turbine-Generator Lubrication Systems | 32 months | 327.5 | General Electric Co. *J. Parkes* |
| RP1649-7 | Reduction of Blade-Passing Frequency Tones of Fossil Power Plant Fans | 2 years | 124.4 | University of Houston *A. Armor* |
| RP1657-1 | Stationary Gas Turbine Catalytic Combustor Development Program | 26 months | 1201.8 | Westinghouse Electric Corp. *L. Angello* |
| RP1673-1 | Assessment of Advanced Geothermal Energy Conversion Concepts | 5 months | 49.9 | The Ben Holt Co. *E. Hughes* |
| RP1702-4 | Feasibility of Using Two-Dimensional Gamma Scanning to Nondestructively Characterize LWR Fuel Rods | 6 months | 35.0 | Los Alamos Scientific Laboratory *H. Ocken* |
| RP1704-12 | EBR-II Superheater SU-710 Performance | 7 months | 9.0 | Argonne National Laboratory *R. Winkleblack* |
| RP1714-2 | Budgetary Estimate for EPRI Software Guidelines Project | 14 months | 25.1 | Technology Development Corp. *J. Lamont* |
| RP1754-3 | Analysis of Bypass Flow Distribution in a BWR | 7 months | 45.0 | Massachusetts Institute of Technology *B. Zolotar* |
| RP1755-1 | High Burnup PWR Isotopics | 5 months | 29.9 | Combustion Engineering, Inc. *W. Eich* |
| RP1771-1 | Develop Methods to Mitigate Corrosion of Copper Concentric Neutral Wires in Conduit | 3 years | 338.5 | Pacific Gas and Electric Co. *R. Stanger* |
| RP1774-1 | Design, Construction, and Testing of a DC Bioeffects Enclosure for Small Animals | 27 months | 450.6 | Battelle, Pacific Northwest Laboratories *R. Kavet* |
| RP1797-1 | Improved Transformer Oil Pump | 22 months | 228.8 | Mechanical Technology, Inc. *J. White* |
| RP1807-1 | Demonstration of Hydrogen Manufacture From Coal Liquefaction Residues | 6 months | 46.1 | Tennessee Valley Authority *R. Wolk* |
| RP1817-1 | Behavioral Effects of Small Air-Ions | 32 months | 701.1 | Rockefeller University *R. Kavet* |
| RP1818-1 | Health Surveillance System for Utility Employees | 1 year | 109.4 | SRI International *W. Weyzen* |
| RP1822-2 | Long-Term pH Data From Lakes | 6 months | 20.0 | SRI International *R. Brocksen* |
| RP1822-3 | Solid Waste Disposal Research Development Plan | 5 months | 19.8 | The Eyman Associates, Ltd. *J. Huckabee* |
| RP1823-1 | Electrochemical Machining Development for Turbine-Generator Rotor Slots | 13 months | 276.0 | Westinghouse Electric Corp. *J. Edmonds* |
| RP1826-1 | Risk-Cost-Benefit Analysis of Selected Toxic Chemical | 8 months | 98.9 | SRI International *P. Ricci* |
| RP1828-1 | Health Effects Review, Evaluation, and Planning | 8 months | 82.6 | University of Michigan *T. Bridge* |
| RP1829-1 | Economic Damage to Vegetation | 15 months | 183.1 | International Research and Technology Corp. *R. Wyzga* |
| RP1860-1 | Test Program for Development and Implementation of TVA AFBC Pilot Plant | 65 months | 18,500.0 | Tennessee Valley Authority *W. Howe* |
| RP1871-1 | Corrosion-Resistant Alloys for Flue Gas Desulfurization Systems | 6 months | 143.3 | Battelle Memorial Institute *C. Dene* |
| RP1901-1 | Phase Equilibrium of Fixed-Bed Gasification Products, Byproducts, and Water | 2 years | 170.0 | Lawrence Berkeley Laboratory *J. McDaniel* |
| RP7876-11 | Development of Low-Temperature Extruded Dielectric Cables | 7 months | 34.2 | Cable Technology Laboratories, Inc. *M. Rabinowitz* |
| RP7881-1 | Cable Monitoring and Rating System (CMARS) Modified for Forced-Cooled and Solid Dielectric Cables | 26 months | 83.0 | Systems Control, Inc. *S. Kozak* |

# New Technical Reports

Each issue of the *Journal* includes summaries of EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

Requests for copies of specific 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, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay the listed price. Research Reports Center will send a catalog and price list on request.

Standing orders for free copies of reports in EPRI program areas or Technical Summaries of reports for each EPRI technical division may be placed by EPRI member utilities, libraries of U.S. federal, state, and local government agencies, and the official representative of any foreign organization with which EPRI has an information exchange agreement. For details, write to EPRI Technical Information Division, Information Distribution Department, P.O. Box 10412, Palo Alto, California 94303.

Microfiche copies are available from National Technical Information Service, P.O. Box 1553, Springfield, Virginia 22151.

## ADVANCED POWER SYSTEMS

**Refractories for Coal Gasification and Combustion Systems**
AP-1268 Topical Report (RP625-1); $3.50

This report reviews current knowledge and practice relating to the use of refractories in slagging and nonslagging coal gasification and combustion systems, with emphasis on the problems of erosion and corrosion. It identifies two areas of concern: (1) erosion of refractory linings in cyclones and gas transfer lines, and (2) slag attack and thermal shock involving refractory linings in slagging gasifiers. A list of references is included. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: John Stringer*

**Entrained-Gasification–Combined-Cycle Control Study**
AP-1422 Final Report (RP913-1);
Vol. 1, $5.75; Vol. 2, $19.75; Vol. 3, $5.75

An integrated plant consisting of an entrained coal gasifier and a combined-cycle unit (gas turbine–steam turbine) was simulated by computer to analyze alternative control strategies. Open-loop response for a stand-alone plant and closed-loop response for a plant functioning in a typical utility power system were studied. Performance during such operating contingencies as equipment trip and emergency shutdown was also evaluated. Both gasifier-lead and gas-turbine-lead control modes were found to be satisfactory. Project results are summarized in Volume 1 and presented in detail in Volume 2. Volume 3 describes the models and calculation procedures used in the study. The contractors are Fluor Engineers and Constructors, Inc., and Westinghouse Electric Corp. *EPRI Project Manager: G. H. Quentin*

**Assessment of Titanium Alloys for Fusion Reactor First-Wall and Blanket Applications**
AP-1433 Final Report (RP1045-3); $4.50

Selection of a material for first-wall and blanket structures in fusion reactors is based on materials availability, fabricability, behavior in the harsh environment of a fusion reactor, fracture properties, and level and duration of induced radioactivity. These factors significantly affect the safety and economics of fusion reactor systems. This report describes the compatibility of titanium in fusion systems and the irradiation behavior, helium embrittlement, and neutronic properties of titanium alloys. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: D. J. Paul*

**Exploratory Studies of High-Efficiency Advanced-Fuel Fusion Reactors**
AP-1437 Annual Report (RP645-1); $4.50

A concept for a field-reversed mirror fusion pilot plant fueled by a mixture of deuterium and helium-3 is described; details are presented on plasma size, power, and startup requirements, as well as energy recovery and system economics. Preliminary studies of possible ways to burn advanced fuels in inertial confinement systems are described. The contractor is the University of Illinois. *EPRI Project Manager: D. J. Paul*

**Geopressured-Energy Availability**
AP-1457 Final Report (RP1272-1); $5.75

This report presents the results of a study to determine the potential for recovering geopressured geothermal energy in the Texas and Louisiana Gulf Coast region and converting it to electricity. The study addressed the issues of energy in place, recoverable energy, electricity generation, waste brine disposal, and economics. It relied primarily on existing data in the geotechnical areas and used statistical analyses to estimate likely production potentials. The contractor is Southwest Research Institute. *EPRI Project Manager: Vasel Roberts*

## COAL COMBUSTION SYSTEMS

**Influence of Coal Mineral Matter on Slagging of Utility Boilers**
CS-1418 Final Report (RP736); $7.25

The operation of five tangentially fired boilers with different slagging histories and fired with different coals was observed. Coal mineral forms and the composition of ash in coal screen and coal density fractions were determined for each type of coal. Furnace ash deposits and fly ash were analyzed, and the temperature and composition of furnace gases measured. The results are used as a basis for exploring how the mineral characteristics of coal affect furnace slagging. The relationship of boiler design to coal variables is also discussed. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: J. P. Dimmer*

**Investigation of High-$SO_2$-Removal Design and Economics**
CS-1439 Final Report (TPS78-760);
Vol. 1, $5.25; Vol. 2, $3.50

This report describes a study to determine the effects of stricter $SO_2$-removal standards on the technology and economics of limestone and magnesium flue gas desulfurization (FGD) processes. Volume 1 presents conceptual process designs and material balances for various cases involving different coals, levels of $SO_2$ removal, and FGD processes. Volume 2 presents the capital costs and incremental revenue requirements for FGD for these cases. The contractors are Radian Corp. and SRI International. *EPRI Project Manager: R. G. Rhudy*

**Dynamics of Power Plant Fan-Foundation Systems**
CS-1440 Final Report (RP984-2); $5.25

A project was conducted to refine and validate a total fan-foundation-soil system model (developed under RP984-1) for predicting the vibratory behavior of large fan systems in power plants. Model predictions and field measurements were compared and found to be in reasonable agreement. The study concluded that contrary to what is generally believed, the stiffest rotor may not provide the best system dynamic response results, and a large foundation may be more sensitive and vibration-prone than a small one. The contractor is Kenneth Medearis Associates. *EPRI Project Manager: I. A. Diaz-Tous*

**Air-Gas System Dynamics of Fossil Fuel Power Plants: Phase 1 Overview**
CS-1444 Final Report, Vol. 1 (RP165); $4.50

Large-amplitude, low-frequency pressure pulsations have occurred in the combustion air–flue gas system of a number of fossil fuel power plants, causing severe equipment damage. This report describes a mathematical model that has been developed to study this problem. An analysis based on pressure and flow wave transmission in ducts is presented that includes the effects of nonlinear fan, damper, and equipment characteristics. The results of the analysis are compared with experimental field data for two oil-fired balanced-draft plants during hot and cold operation. The contractors are Westinghouse Electric Corp. and the Massachusetts Institute of Technology. *EPRI Project Manager: I. A. Diaz-Tous*

**Centrifugal Pump Hydraulic Instability**
CS-1445 Final Report (RP1266-18); $3.50

Problems with boiler feed pumps are a leading cause of unscheduled outages in large fossil fuel power plants. This study describes the origins of hydraulic instability in centrifugal pumps for boiler feed applications and categorizes the effects in terms of stage geometry and hydraulic mechanisms. Theoretical explanations of these mechanisms are reviewed, as well as the status of experimental research. Laboratory measurement of the static and dynamic forces that act on a pump impeller is described. The contractor is Energy Research & Consultants Corp. *EPRI Project Manager: I. A. Diaz-Tous*

### Materials Problems in Fluidized-Bed Combustion Systems: High-Temperature Erosion-Corrosion by High-Velocity Particles

CS-1448 Final Report (RP979-4); $8.25

This report presents the results of erosion and erosion-corrosion experiments performed on state-of-the-art turbine materials (nickel- and cobalt-base superalloys, aluminide coatings for these alloys, and silicon nitride) in a burner rig at temperatures of 871°C and gas velocities of 200 m/s. Alumina, magnesia, and coal dust were used as the abrasive agents. Salt was used as the corrosive agent. Conditions simulated those in a coal-fired gas turbine. The contractor is Pratt & Whitney. *EPRI Project Manager: John Stringer*

### Condenser Biofouling Control

CS-1450 Symposium Proceedings; $39.95

Biofouling on the water side of operating condensers decreases their heat transfer efficiency and, as a result, overall plant efficiency. In the past, chlorine has been used to control biofouling, but increasing federal regulation of chlorine discharge poses difficult questions regarding its use. EPRI sponsored a symposium in Atlanta in March 1979 to examine biofouling control; this hardbound volume reproduces most of the papers presented there. They discuss the nature and cost of the problem, biofouling mechanisms, biofouling measurement, and control options. *EPRI Project Manager: Winston Chow*

### Two-Phase Flow and Heat Transfer in Fluidized Beds

CS-1456 Final Report (RP525-1); $12.00

This report describes cold modeling studies on ambient-temperature fluidized beds. Data on flow regimes, bed expansion (void fraction), transverse thermal conductivity, and bare- and finned-tube heat transfer are presented for beds of narrow and wide particle-size distributions fluidized with air and a refrigerant at room temperature. Generalized predictive models for bed flow regimes, bed expansion, solids circulation rates, and heat transfer to tube banks are described. The contractor is General Electric Co. *EPRI Project Managers: C. J. Aulisio and T. E. Lund*

### Environmental and Chemical Analysis Technician Curriculum Planning Guide

CS-1464 Final Report (RP1266-6); $10.50

A model curriculum for use in training power plant environmental and chemical analysis technicians is presented. A detailed task inventory of the job was performed and used as the basis for the two-year curriculum. The contractor is the Center for Occupational Research and Development. *EPRI Project Managers: J. P. Dimmer and K. P. Lehner*

### Technical Planning Study: Pressurized Fluidized-Bed Combustion

CS-1465 Final Report (TPS78-762); $8.25

The status of pressurized fluidized-bed combustion research and development is assessed, and specific areas requiring additional work are identified. The report presents 14 key technology milestones that must be achieved to ensure a successful demonstration plant; the most important is the selection of a reliable hot-gas-cleanup system–gas turbine combination. The contractor is General Electric Co. *EPRI Project Manager: W. W. Slaughter*

### Wet-Dry Cooling for Cycling Steam-Electric Plants

CS-1474 Final Report (RP1182-1); $5.25

This report presents the results of a detailed evaluation of the economics of wet-dry cooling for large steam-electric plants designed for cycling or intermediate-load duty. A system simulation and design optimization computer model was used to determine the optimal economic trade-off between wet-dry cooling capacity and loss of plant performance. Results show that the optimal design for all-wet or all-dry systems is essentially independent of the assumed plant capacity factor. The contractor is Dynatech R/D Co. *EPRI Project Manager: J. A. Bartz*

### Workshop Proceedings: Low-Pressure Steam Turbine Blade Failures

WS-78-114 Workshop Report; $5.25

In June 1978 EPRI sponsored a workshop in Detroit to investigate low-pressure steam turbine blade failures. Utility concerns were discussed, as well as EPRI projects for improving blade reliability. This report summarizes presentations, discussions, and recommendations for future research. The contractor is Failure Analysis Associates. *EPRI Project Managers: K. R. Kinsman and R. H. Richman*

## ELECTRICAL SYSTEMS

### Electronic Current Transducer for High-Voltage DC Lines

EL-1343 Final Report (RP668-1); $7.25

This report describes (1) the development of a biopolar electronic current transducer (ECT) for measuring the current in a high-voltage dc power line at line potential, and (2) the design and construction of a free-standing ECT prototype for use on a 400-kV line with a nominal line current of 2000 A. The new ECT provides analog and digital outputs suitable for metering, zero-current detection, protective static relaying, and control purposes. The performance of the prototype is discussed in the light of initial specifications. The contractor is General Electric Co. *EPRI Project Manager: S. L. Nilsson*

### Extruded Dielectric DC Cable Development

EL-1386 Final Report (RP7828-1); $10.50

The development of an extruded 100-kV dc cable insulated with a mineral-filled polymeric dielectric is described. A mathematical model relating critical insulation properties to dc cable performance was developed. Several types of base resins, mineral fillers, chemical filler treatments, and antioxidants were tested for their effects on coefficient alpha, dielectric strength, and volume resistivity. Dielectric strength evaluations and screening tests were conducted on candidate materials. A prototype cable was manufactured and tested. The contractor is General Electric Co. *EPRI Project Manager: F. G. Garcia*

### Determination of Synchronous Machine Stability Study Constants

EL-1424 Final Report, Vol. 3 (RP997-3); $14.25

Load rejection tests were performed on two utility generators to derive machine model parameters, which were then used in state-of-the-art second-order models in computer simulations of line-switching tests. There was good correlation between the simulation results and the results of actual line-switching tests. The contractor is Power Technologies, Inc. *EPRI Project Manager: D. T. Bewley*

### Gas-Vapor and Fire-Resistant Transformers

EL-1430 Final Report (RP930-1); $12.00

Transformers in partially enclosed locations must use cooling and insulating materials that are more fire-resistant than oil. This report describes an effort to develop new designs with new materials for such transformers. Three prototypes were developed and subjected to design testing: a 15-kV, 2500-kVA gas-vapor transformer that uses both $SF_6$ and a fluorocarbon liquid and two 34.5-kV transformers, one 1000 kVA and the other 5000 kVA, in which the core and coil assembly is totally immersed in a mixture of perchloroethylene and oil. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. S. Tackaberry*

### Impregnation of Solid Dielectric Cable Insulation

EL-1435 Final Report (RP7854); $10.50

This report describes laboratory-scale investigations of the feasibility of impregnating the microvoids in cross-linked polyethylene cables with catalyst-bearing monomers and then polymerizing the monomers into a solid to prevent diffusion out of the cable. Process conditions for impregnation with various liquids and for polymerization were studied, and the dielectric strength of the treated samples was periodically measured to monitor cable improvement. The economics of the process were analyzed. The contractor is Phelps Dodge Cable & Wire Co. *EPRI Project Manager: F. G. Garcia*

### Fundamental Investigation of Arc Interruption in Gas Flows

EL-1455 Final Report (RP246-2); $8.75

The thermal (early) phase of the recovery process in gas-blast interrupters was studied. Specific project tasks were to develop aerodynamic diagnoses of cold flow fields for various electrode-nozzle configurations, to determine the dependence of thermal interruption speed on nozzle throat diameter, and to document the thermal interruption speeds of different gases (particularly $SF_6$) and gas mixtures. The contractor is General Electric Co. *EPRI Project Manager: N. G. Hingorani*

## ENERGY ANALYSIS AND ENVIRONMENT

### Coal Resource Information: Case Studies in Evaluating Adequacy of Information

EA-673 Final Report, Vol. 3 (RP868-1); $10.50

This report describes detailed analyses of the quality and completeness of existing coal resource information for two representative regions: Campbell County, Wyoming, and Pike County, Kentucky. Findings of a general nature, as well as case-specific findings, are reported. The contractor is ICF Incorporated. *EPRI Project Manager: J. B. Platt*

### Evaluation of a Cooling-Lake Fishery: Introduction, Water Quality, and Summary

EA-1148 Final Report, Vol. 1 (RP573); $4.50

This volume presents detailed limnological descriptions and water quality comparisons for two study areas, a cooling lake that receives power plant thermal effluent and a nearby flood control reservoir. Principal parameters of interest were water temperature, dissolved-oxygen concentration, and turbidity. A summary of Volumes 2–4 is included. The contractor is the Illinois Natural History Survey. *EPRI Project Manager: J. Z. Reynolds*

**Analysis of AEC–ERDA–DOE and USGS Uranium Program Data: Discipline Reviews and Summary Reports**
EA-1374 Final Report (RP870-1); $16.50

This report summarizes and analyzes the findings of a review of nearly 2500 reports and publications by U.S. government and nongovernment groups during the period 1950–1977. It discusses the various types of uranium deposits, the geologic and structural environments in which they occur, and the mechanisms for their emplacement. The various techniques used to explore for, evaluate, and exploit uranium deposits are also considered. Brief summaries of the documents reviewed are available through Oak Ridge National Laboratory's computerized literature search service. The contractor is Dames & Moore. *EPRI Project Manager: J. B. Platt*

**Probabilistic Simulation of Multiple Energy Storage Devices for Production Cost Calculations**
EA-1411 Final Report, Vols. 1 and 2 (TSA78-804); $10.50

A computationally feasible probabilistic production cost model was developed for evaluating the impact of multiple energy storage technologies (such as pumped hydro, storage batteries, cryogenic storage, flywheels, and compressed-air storage) on utility operating costs. The model is oriented toward, but not limited to, the Wien Automatic System Planning Package, a widely used generation system expansion planning model. The report includes computer codes. The contractors are Brian Manhire and Ohio University. *EPRI Project Manager: Dominic Geraghty*

**Combined Energy Models**
EA-1420 Interim Report (RP1016-2); $5.75

Typically, large-scale energy models grow through the combination of several smaller models. An examination of the methodologies used in various efforts to develop combined energy models revealed a common framework for organizing and manipulating the models and establishing the properties of the solutions. This report describes existing modeling techniques within this framework, the application of these techniques to other models, and an approach to the development and application of combined models. The contractor is Harvard University. *EPRI Project Manager: Richard Richels*

**Atmospheric and Terrestrial Effects of Closed-Cycle Cooling Systems: An Annotated Bibliography**
EA-1438 Interim Report (RP877); $6.50

This bibliography presents abstracts for almost 600 references on the environmental effects of closed-cycle cooling operations. Topics covered include atmospheric discharges from cooling towers, predicted cumulative effects of releases from energy parks, sensitivity of crops and native vegetation, salt deposition, esthetic impacts, atmospheric dispersion and plume behavior, and analytic methods. The references are from the open literature and environmental reports and impact statements up to spring 1979. Indexes are included. The contractors are Atomic Industrial Forum, Inc., and Oak Ridge National Laboratory. *EPRI Project Manager: I. P. Murarka*

**Assessment of the Effects of Uncertainty on the Adequacy of the Electric Utility Industry's Expansion Plans, 1983–1990**
EA-1446 Interim Report (RP1153-1); $8.75

This study used current information, models, and decision analysis techniques to develop a modeling framework for regional U.S. utility planning that deals explicitly with uncertainty in electricity demand growth and enables evaluation of the cost-effectiveness of alternative capacity expansion plans. To assess the adequacy of current regional power supply plans, 17 capacity expansion cases were simulated for each of seven demand growth possibilities in nine regions for three analysis years. The contractor is the University of Texas at Austin. *EPRI Project Managers: E. N. Oatman and H. P. Chao*

**Modeling of Dry Deposition of $SO_2$ and Sulfate Aerosols**
EA-1452 Final Report (RP1306-1); $4.50

A mathematical model of the dry deposition of $SO_2$ and sulfate aerosols was developed and systematically simplified for use in the SURE regional air quality model. The results of calculations are presented to demonstrate the sensitivity of deposition to atmospheric stability, surface resistance, plant area density and structural shape, aerosol particle size, Rossby number, and canopy Reynolds number. The contractor is Aeronautical Research Associates of Princeton, Inc. *EPRI Project Manager: G. R. Hilst*

**Integrated Models for R&D Planning**
EA-1462 Interim Report (RP1108-1); $2.75

This report describes the current version of the Integrated Forecasting Model, a model of the U.S. energy sector being developed for use by EPRI R&D planners. Topics covered include model theory and design, submodels, model logic enhancements, the generalized equilibrium modeling approach, and network implementation. The new model was tested by developing a data set and running a base case and five sensitivity cases. The contractor is Decision Focus, Inc. *EPRI Project Manager: L. J. Rubin*

## ENERGY MANAGEMENT AND UTILIZATION

**Development of the Zinc Chloride Battery for Utility Applications**
EM-1417 Interim Report (RP226-3); $15.25

This report reviews progress in Phase 2 (April 1978–March 1980) of a program to develop the zinc chloride battery for utility load-leveling applications. Tasks in this phase included refurbishment of a 45-kWh module to increase capacity and efficiency, cycle testing of a 1.7-kWh battery, and development of a 50-kWh module to serve as the building block for the 4-MWh battery for the Battery Energy Storage Test Facility. The contractor is Energy Development Associates. *EPRI Project Manager: D. L. Douglas*

**Evaluation of Load Management Systems and Devices**
EM-1423 Final Report (TPS78-807); $7.25

The technical and operating characteristics of communication and load control systems, local control devices, and end-use thermal storage systems are discussed. A costing analysis is developed for each system and device. Payback figures are derived for the thermal storage systems on the basis of uniform operating scenarios under two rate structures. The contractor is EUS, Inc. *EPRI Project Manager: Quentin Looney*

**Dual Energy Use Systems: District Heating Survey**
EM-1436 Final Report (RP1276-3); $6.50

A survey of 59 utilities that operate district heating systems was conducted, and executives of various utilities (including some that operate these systems and some that do not) were interviewed. The information was used to compile 10 case studies of utilities that operate district heating systems under a broad range of circumstances. In addition to describing these activities, this report summarizes available literature on district heating in the United States and abroad and presents recommendations for future studies. The contractors are EUS, Inc., and Hittman Associates, Inc. *EPRI Project Manager: R. L. Mauro*

## NUCLEAR POWER

**Human Factors Methods for Nuclear Control Room Design: Human Factors Considerations for Advanced Control Board Design**
NP-1118 Final Report, Vol. 4 (RP501-3); $5.25

This report describes human factors aspects of the development of advanced, multi-cathode-ray-tube control board designs. It covers information-accessing schemes, display system parameters, information coding, display formatting, advanced warning systems, and interface hardware. It also reviews hybrid concepts, which integrate conventional and advanced approaches, and discusses the results of a survey of control board designers. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Managers: H. L. Parris and R. W. Pack*

**Proliferation-Resistant Technology Assessment**
NP-1306 Final Report (RP1253-3); $5.75

An investigation was made of two possible methodologies for semiquantitatively measuring the transferability (to a nuclear weapons development effort) of technology associated with (1) commercial nuclear power generation and its supporting activities, and (2) nonnuclear industrial activities. Available data on facility capital and operating costs and on industrial activity levels in various nations were used in applications of the two methodologies. The contractor is Advanced Technology Associates, Inc. *EPRI Project Manager: R. F. Williams*

**COPHIN Code Description**
NP-1385 Final Report (RP1252-3); $4.50

This manual describes the methodology, input preparation, and output for the COPHIN code, which processes the output of the single-assembly analysis codes CPM and CASMO into the input required for multiassembly depletion analysis by the PDQ/HARMONY code. The contractor is Science Applications, Inc. *EPRI Project Manager: W. J. Eich*

**Computational Modeling of Microstructural Fracture Processes in A533B Pressure Vessel Steel**

NP-1398 Final Report (RP1023-1); $5.25

Smooth and notched round-bar specimens of A533B steel were tested under tension. The observed failure mode was nucleation, growth, and coalescence of ductile voids. Data from the smooth-bar test were used to construct a computational void kinetics model. Calculations of critical parameters are presented, and other model applications are discussed. The contractor is SRI International. *EPRI Project Manager: T. U. Marston*

**Prediction of Annular Liquid-Gas Flow With Entrainment: Cocurrent Vertical Pipe Flow With No Gravity**

NP-1409 Topical Report (RP1380-1); $5.25

An adiabatic two-phase annular model with liquid entrainment was derived for flow in a pipe with negligible gravity effects. The model divides the flow cross section into three regions: a liquid film, a gas core of constant density, and a transition layer between them. A constant velocity and a density that varies exponentially with distance from the wall are used in the transition layer. Model results were compared with air-water and steam-water test data, and a simplified model was developed to permit rapid approximate calculations. The contractor is S. Levy, Inc. *EPRI Project Manager: K. H. Sun*

**Application of RETRAN to Complex Geometries: Two-Dimensional Hydraulic Calculations**

NP-1415 Interim Report (RP958); $9.50

Several limitations of the one-dimensional, nonvector form of the momentum equation in RETRAN, a transient thermal-hydraulic system analysis code that represents the current state of the art, have been identified. This report describes the development and limited application of a vector momentum equation suitable for RETRAN. The calculations and data comparisons presented indicate that some deficiencies of standard RETRAN are eliminated by the vector momentum model. The contractor is Energy Incorporated. *EPRI Project Manger: L. J. Agee*

**Signal Processing for ISI**

NP-1421 Interim Report
(RP1125-1, RP1125-1-1); $8.75

This report describes progress in a continuing effort to apply nonlinear signal processing to the in-service inspection (ISI) of pipes and nozzles in nuclear reactors, and to develop adaptive learning networks for eddy-current signal analysis. Areas of activity in this project phase included design and fabrication of nondestructive evaluation instruments; detection and sizing of stainless steel pipe cracks, feedwater nozzle cracks, and steam generator tubing defects; eddy-current signal analysis; and nondestructive evaluation of wood poles. The contractor is Adaptronics, Inc. *EPRI Project Manager: G. J. Dau*

**STEALTH Modeling of Time-Dependent Flows in Piping**

NP-1441 Final Report (RP812-1); $8.75

This report documents technologies that enable the one-dimensional STEALTH code to simulate the time-dependent flow phenomena that can occur in power plant piping systems. These technologies include fixed-frame control volume models, a fluid motion loss model, a force resolution model, and plot overlays to enable display of several nodal histories on one axis system. Appendixes describe one-dimensional numerical simulations of pipe flows that are generic to power plant systems. The contractor is Science Applications, Inc. *EPRI Project Manager: J. J. Carey*

**Analysis of Separated-Flow Models**

NP-1442 Interim Report (RP888-2); $5.25

Research was undertaken to examine the formulation of models for transient two-phase flow. Averaged conservation equations and interfacial jump conditions were derived. The implications of averaging were examined by considering wave propagation in stratified flow and comparing the results with a finite-amplitude wave analysis of the local instantaneous equations. The contractor is Banerjee & Associates Consultants, Inc. *EPRI Project Manager: L. J. Agee*

**Methodology and Application of Probabilistic Evaluation to Thermal Reactor Safety**

NP-1443 Final Report (RP297-1); $7.25

This report summarizes work to develop and apply probabilistic risk analysis techniques. It covers common-cause failures, a methodology for computer-aided fault tree construction, the derivation of expressions for the average unavailability of periodically tested redundant systems, noncoherent fault tree analysis, and the calculation of confidence intervals by moment propagation in fault trees. The contractor is the University of California at Los Angeles. *EPRI Project Manager: B. B. Chu*

**Evaluation and Test of Improved Fire-Resistant Fluid Lubricants for Water Reactor Coolant Pump Motors**

NP-1447 Final Report (RP893-1);
Vol. 1, $12.50; Vol. 2, $11.25

Commercially available fire-resistant fluid lubricants were evaluated to determine their suitability for use in primary-system pump motors in nuclear reactors. Volume 1 describes the procedures and results of tests of lubrication properties; fire and radiation resistance; and thermal, oxidative, and hydrolytic stability. Volume 2 describes tests of the lubricants' compatibility with metallic systems, electrical insulation and corona-suppression systems, structural and stator-winding components, paints, and elastomers. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. E. Swanson*

**Review of PWR Fuel Rod Waterside Corrosion Behavior**

NP-1472 Interim Report (RP1250-1); $5.25

This state-of-the-art report reviews published data on Zircaloy corrosion in PWRs and presents previously unpublished measurements of the thickness of oxide films on fuel rods in German PWRs. A nondestructive eddy-current technique was used to make these measurements, and their accuracy was confirmed by destructive examination. The data show that in-reactor corrosion rates are greater than rates determined from out-of-reactor measurements, but the increase varies widely from reactor to reactor and from cycle to cycle. The contractors are Kraftwerk Union Ag and Combustion Engineering, Inc. *EPRI Project Manager: Howard Ocken*

**Proceedings: Seminar on Countermeasures for Pipe Cracking in BWRs**

WS-79-174 Workshop Report; Vol. 1, $22.75;
Vol. 2, $16.00; Vol. 3, $12.00; Vol. 4, $12.00

These volumes present papers from a seminar on countermeasures for intergranular stress corrosion cracking (IGSCC) held in Palo Alto, California, in January 1980. Volume 1 contains an overview of the problem and papers on IGSCC models, theoretical considerations, cladding, stress improvement by inside water cooling and by induction heating, models for controlling weld residual stresses, and qualification of countermeasures. Volume 2 covers experimental activities; Volume 3, deaeration and alternative materials; and Volume 4, implementation of countermeasures, inspection, and repairs. Volume 4 also presents a summary of the seminar. *EPRI Project Managers: J. C. Danko and R. E. Smith*

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



EPRI

**ADDRESS CORRECTION REQUESTED**