Directions in Fuel Supply

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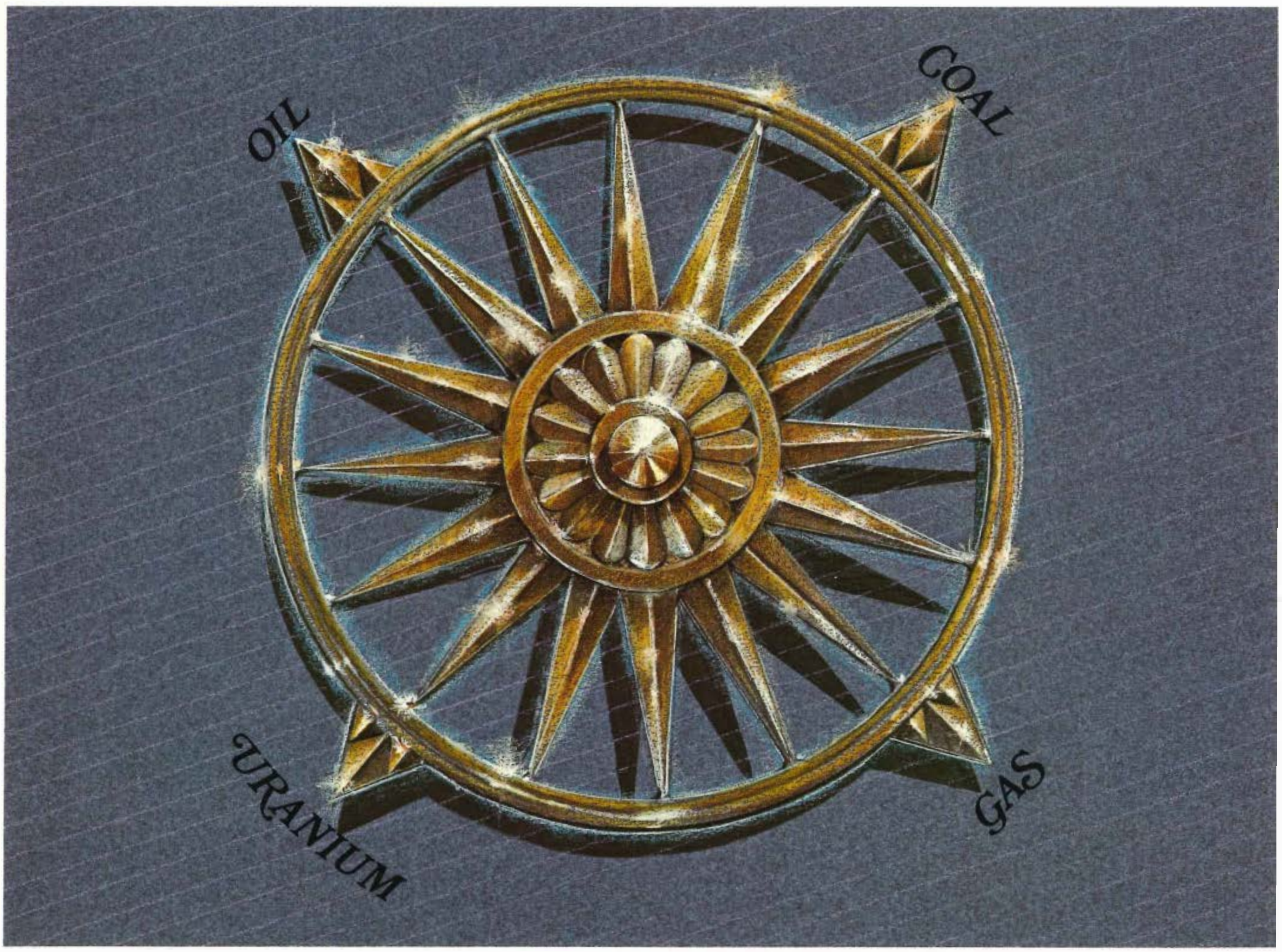

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Cover: Utilities will be increasingly interested in switching fuels to take advantage of price swings and to maintain flexibility in a highly uncertain environment for boiler fuels.

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Fuel Planning in the 1980s

Fuel supply management has been thrust into the limelight of utility issues by a number of events: fuel costs have soared, prices for different fuels have not increased in parallel, contract sanctity is no longer assured, and governments have intervened in the fuel markets. Future conditions appear even more uncertain than in the past, and regulators are holding some utilities responsible for unfavorable outcomes. There was a time when the fuel planner's job focused on two elements: ferreting out the best price he could obtain and writing a contract that would ensure continuous, quality fuel delivery under satisfactory terms. There were times when this proved difficult. For example, when the uranium market was booming in the mid 1970s, finding a reasonable deal called for innovative sleuthing and negotiations. Similarly, when coal markets were tight, buying and developing one's own coal property took much skill.

Today's fuel planning problems are not driven by shortage but by uncertainty stemming from substantial changes that are affecting the energy markets and energy use. Will gas be available to utilities for boiler fuel? Will the government allow oil to be burned? What regulations will be placed on the kind of coal that may be burned and will, for example, low-sulfur coal be available at a reasonable price? These uncertainties have put the best-laid plans into chaos. Moreover, now that fuel costs in the United States have climbed from an average of 15% of revenue to over 40%, keeping these costs in line and even reducing them is a first-order priority for utilities. The planning tools to do this job are beginning to catch up in sophistication to other utility analytic techniques—for example, the sophisticated analyses traditionally used by the utility industry in planning capital investments.

This month's lead article focuses on the needs of the fuel planner and the tools being developed or already available for his use. These tools have also been described at a series of EPRI fuel conferences and seminars. The sold-out attendance at these affairs testifies to the recognized need for better information and analytic techniques in fuel planning. One common assumption built into these tools is the need to hedge against uncertainty—uncertain demand, uncertain price, and uncertain supply. In some measure this flies in the face of traditional utility planning, which viewed ensured availability of electricity as nearly the sole criterion. Hedging is a strategy to bring ensured supply into balance with a utility's cost objectives.

For the most part, the actual outcome of these new efforts will not be known for years or even decades. If current experience is any indication, some regulators in the future will not be sympathetic to results that could have been improved upon by the selection of a different strategy. The major objective of the new generation of fuel planning tools is to ensure that these "best" decisions are selected in the first place. But an increasingly important objective is to provide the clear documentation required to demonstrate that the fuel decisions were in the best interest of the customers, given the facts at hand when the decision was made. The analytic techniques now emerging offer both help in making the best decisions and documentation of the rationale for making them.

René Malès, Vice President
Energy Analysis and Environment Division

Authors and Articles

Planning for capital spending has always held high priority among utilities. But since 1970 a dramatic shift in fuel's share of total cost has added a critical new dimension to the planner's tasks. One result of the change is that some long-held assumptions about fuel purchasing are being challenged, with the aim of improving supply flexibility. **Fuel Supply Management: Charting a Course Through Uncertainty** (page 6) explores new methods under development to help utilities integrate fuel planning with the rest of corporate planning.

The author, science writer John Douglas, drew material from a recent EPRI fuel supply seminar and from studies managed by the Energy Analysis and Environment Division. Most of the research is in the division's Energy Resources Program. Eugene Oatman has managed the program since May 1980; he joined the Institute in 1978 as a senior member of the systems program technical staff. His experience as a planning specialist includes 14 years at The Dayton Power and Light Co. Oatman earned an electrical engineering degree at Case Institute of Technology and an MBA from Wright State University in Dayton, Ohio.

Stephen Chapel, who manages research in fuel planning methodology, engineering-economic issues, and technology commercialization, joined EPRI in 1980 after four years with The Rand Corp. as a senior economist. Before that, he was deputy director of DOE's Office of Economic Impact, worked in the DOD's Office of Systems Analysis, and briefly was director of special studies in the General Services Administration. Chapel received a BS in applied mathematics and an MS in economics from the University of Wyoming.

Howard Mueller, a project manager in fuel planning and management, directed Maryland's power plant site selection program and energy economic studies before joining EPRI in 1982. Previously, Mueller worked as a research chemist with Armco Steel Corp. He received a BS from Dartmouth College and did graduate work in economics at the University of Cincinnati.

Jeremy Platt is responsible for projects involving the geology of energy resources, resource estimates, supply forecasting, and regional fuel markets. Before joining EPRI in 1974 Platt worked in resource-related positions with American Smelting and Refining Co. and Mobil Oil Corp. At Harvard University he focused on geology and economics; his MS in geology is from Stanford University.

Hung-Po Chao, an operations research manager in the Institute's Decision Methods and Analysis Program, provided another perspective for the story. Chao was a research associate at Stanford University when he came to EPRI in 1979. He received a BS in electrical engineering from Taiwan University, MS degrees in operations research and statistics, and a PhD degree in operations research from Stanford University.

■

When a utility has a technical problem in stack gas control on a fossil fuel boiler, finding a solution can often mean costly downtime. An EPRI service, now nearly 10 years old, helps keep downtime and extra expense at a minimum by making technical expertise only a telephone call away. **Quick Response to Stack Gas Queries** (page 14) was written by John Douglas with the technical assistance of Stuart Dalton and Charles Dene in the Coal Combustion Division.

Dalton, program manager for desulfurization processes since 1979, joined EPRI in October 1976 as a project manager. Before that, Dalton was an engineer for four years with Pacific Gas and Electric Co. after spending three years with Babcock & Wilcox Co. He is a chemical engineering graduate of the University of California at Berkeley.

Charles Dene, desulfurization project manager, joined EPRI in 1978 and worked as facilities manager for two pilot plant studies at the Shawnee Test Facility in Paducah, Kentucky. Previously, he worked for Acurex Corp. as a pilot plant manager and was a research engineer in water quality and pollution control equipment with Detroit Edison Co. from 1973 to 1977. Dene graduated in chemical engineering from Wayne State University.

■

The changing shape of the American economy and its implications for the energy sector were the general topics of conversation when EPRI's Advisory Council convened recently in San Diego. What seemed to emerge from the discussions was a new reality of international economic competition, one in which electric power will likely play a crucial role in revitalizing basic industries. Brent Barker, the *Journal*'s editor in chief, distills and interprets the comments and mood of the gathering in **Energizing American Industry for Global Competition** (page 16).

Editor of the *EPRI Journal* since 1977, Barker previously worked for the Institute as a writer and communications consultant. From 1968 to 1973, he was an industrial economist with SRI International's Long Range Planning Service, where he researched the future of emerging industries and technologies. Before that, Barker was a forecasting analyst with U.S. Steel Corp. He received a degree in engineering science from Johns Hopkins University and an MBA from the University of Pittsburgh.

■

Modeling the reliability of an entire power plant is now possible. **Finding the Weak Links in Power Plant Availability** (page 26) reviews how it is done and what it can mean for comparing the costs, the effects, and the value of redundant components, revised maintenance routines, or larger inventories of spare parts. To develop the story, science writer Adrienne Harris Cordova turned to the EPRI researcher responsible for the new development.

Jerome Weiss is a project manager in the Engineering and Economic Evaluation Program of the Advanced Power Systems Division. Comparisons of plant configurations and entire generation technologies, still at the paper stage, have been his specialty since 1976. Before that, Weiss was a research scientist with Lockheed Missiles & Space Co. for 14 years, and from 1965 to 1974 he was also an adjunct faculty member at Stanford University. Weiss's earlier career includes 3 years with The Rand Corp. and 9 years with the U.S. Signal Corps Engineering Laboratories. He has a BS in physics from the City College of New York and an MS in statistics from Stanford University.

Dalton

Barker

Weiss Dene

Chao Mueller Oatman Chapel Platt

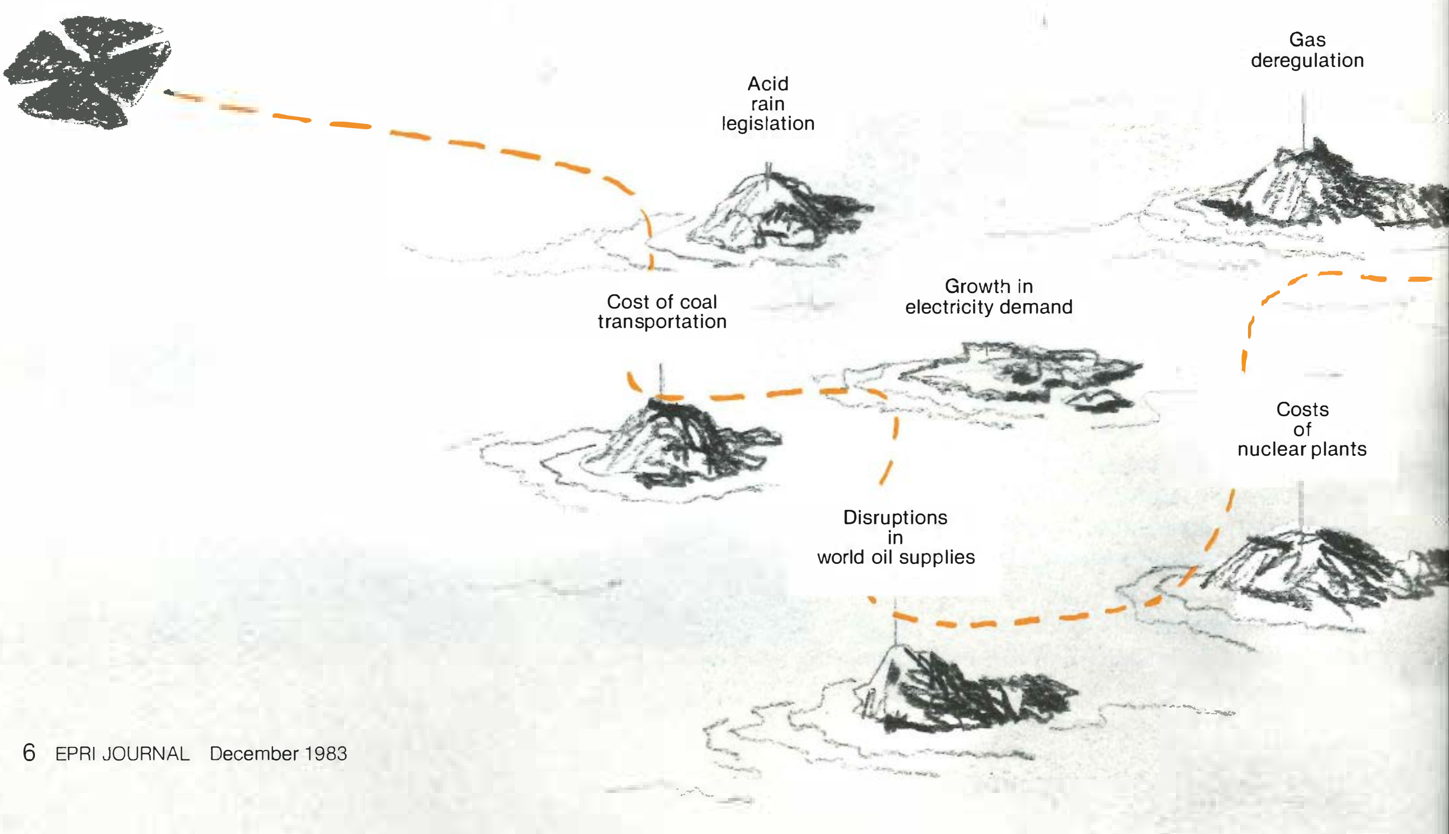
Over the last decade the economics of electric power generation has undergone a gradual but fundamental change. Fuel costs have increased from around 15% of total utility expenditures in 1970 to more than 40% today. For many utilities that do not rely heavily on hydro or nuclear power, fuel costs can account for more than half of their total expenditures. To accommodate this shift, utility executives are changing the way they try to contain costs and handle other fuel-related issues.

Because the electric utility industry is the most capital-intensive of all, management emphasis in planning for the future has traditionally focused on capital expenditures. That effort is still important; but in addition, fuel supply planning and analysis have now become critical concerns for many utilities. At the same time, major shifts in the availability and economy of various fuel types have created uncertainties that make planning more complex.

Some of the traditional assumptions about how fuel purchases should be made are now being challenged. Writing recently in *Public Utilities Fortnightly*, energy consultants John Sawhill and

Fuel Supply Management: Charting a Course Throug

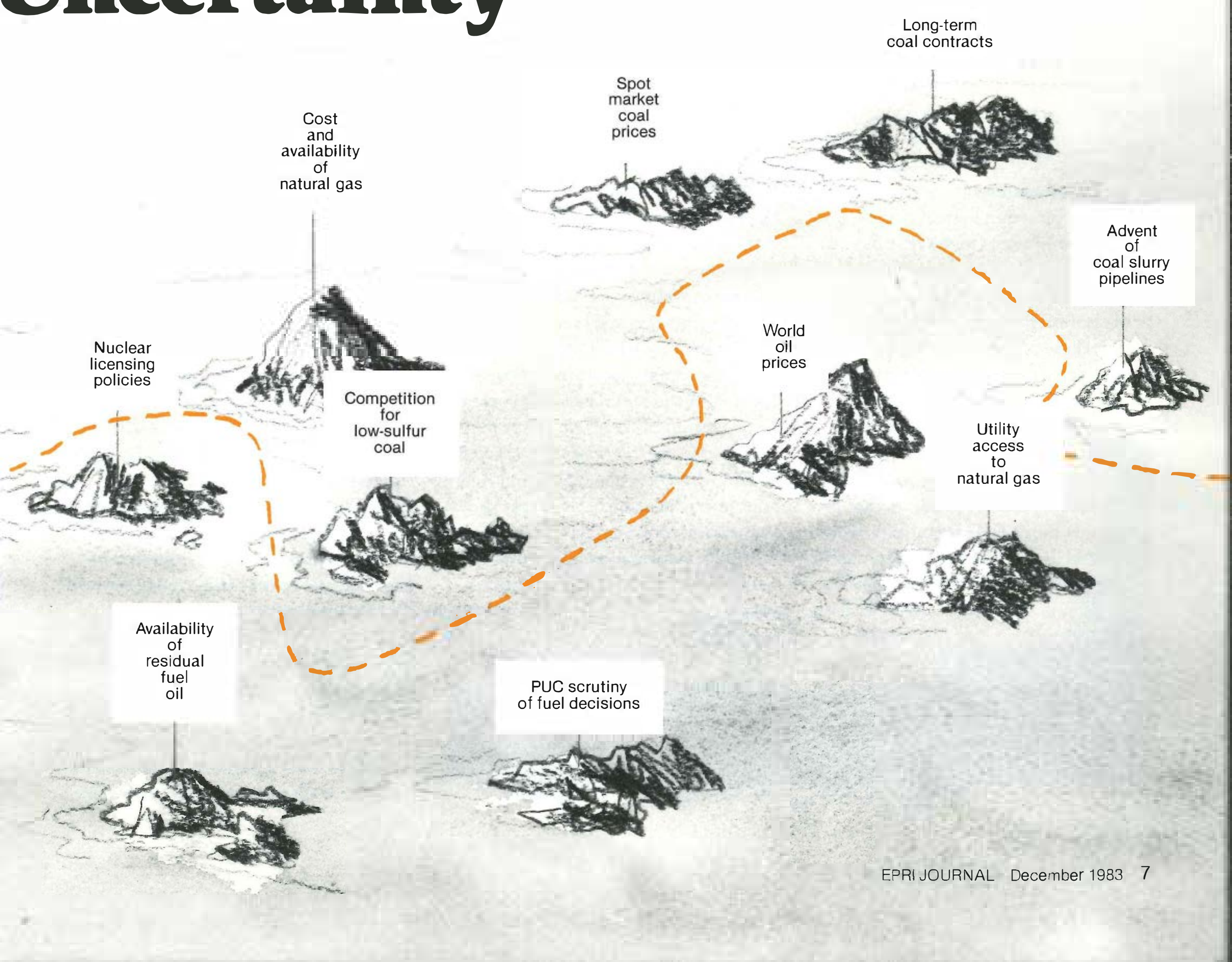
Fuel planners must pilot utilities through a sea dotted with economic and regulatory unknowns. With the added threat of supply disruptions, utilities need better analytic tools and more-flexible procurement and inventory strategies to keep the cost of boiler fuels in line.



Richard Messina cited three time-honored practices that particularly need review. Exclusive reliance on long-term fuel contracts, they believe, has become less attractive than a portfolio approach that includes both long- and short-term commitments. More fuel-related services, like transportation and storage, could be handled by utilities themselves to reduce reliance on one or two full-service suppliers. And, they conclude, a more flexible strategy of maintaining the ability to switch fuels to take advantage of inevitable market changes is now frequently more desirable than simply planning to maintain a stable fuel mix.

To help the industry deal with changes in the fuel supply outlook, EPRI is developing methods to help fuel planners select and document new fuel strategies. EPRI is also providing information about fuel markets, which utilities can use in characterizing and understanding the uncertainties that exist in those markets. "Fuel supply planning has become a leading concern for many utilities," says Eugene Oatman, manager of the Energy Resources Program in EPRI's Energy Analysis and Environment Division. "Yet this is one of the areas of expense

Uncertainty



over which they can exercise the most control. What we can do is help give them the analytic tools needed to integrate fuel planning with the rest of corporate planning."

Difficult choices

Several factors have coincided to heighten fuel supply uncertainties and present fuel planners with increasingly difficult choices. First, the Arab oil embargo sent a shudder through the industry, demonstrating just how uncertain fuel supplies could be. Subsequent price increases showed that even if available, oil would be subject to entirely new economies of use.

Second, the apparent viability of other fuels has also become more uncertain. The accident at Three Mile Island cast a shadow over nuclear power. Concern over acid deposition has made the future cost of electricity from coal increasingly uncertain. Wide discrepancies plague various estimates of how much natural gas will be available, and deregulation further complicates efforts to predict its future price.

Third, and perhaps most important, a prolonged recession has cut deeply into utility commitments to the new baseload plants that would have played a vital role in replacing oil with domestic coal or nuclear fuel.

How these uncertainties affect different utilities will vary considerably according to individual circumstances. Take, for example, the problems facing oil-dependent utilities in crowded urban areas of the Northeast.

"Air quality issues are paramount to a utility that burns large quantities of oil but would like to convert to coal," comments Robert A. Bell, vice president of Consolidated Edison Co. of New York, Inc. "Concern over acid deposition makes the transition difficult. It may drive us to scrubbers or it may drive us to low-sulfur coal. Yet," he continues, "some sort of conversion must be made. We just have to reduce the amount of oil we are importing into this country. Strategically, importing makes us vulnerable, and we're also vulnerable in a business sense—another oil embargo could have a very serious impact on our company's position."

Although this sort of difficult decision making was prompted initially by growing uncertainties in fuel supply, an increased need for utilities to be able to formally justify their choices has complicated the situation even further. "Over the past decade we've come to live with uncertainty," explains Lawrence C. Grundmann, Jr., vice president for engineering of System Fuels, Inc., a subsidiary of Middle South Utilities, Inc. "I think the biggest change is coming about in the various publics that the utilities have to deal with, including both regulatory agencies and customers. They have developed a propensity to second-guess utility decisions and to judge them by present circumstances rather than by the situation that existed when the decisions were made."

Fuel supply futures

Despite the numerous uncertainties inherent in studies of fuel supply, some trends are becoming clear. To facilitate the sharing of these insights between EPRI contractors and utility planners, the Energy Resources Program staff holds a series of annual fuel supply seminars during which the results of ongoing research projects are reviewed. The goal of the seminars is not to create a new fuel supply forecast, per se, but to discuss existing forecasts—why they differ and what their limitations are. A brief review of some of the papers delivered at last year's seminar, together with some information from other sources, can help reveal what various experts believe about the future of utility fuel supplies.

Coal, everyone seems to agree, is plentiful. Daniel Klein of ICF, Incorporated, estimates that coal production will almost double by the end of the century and that depletion will cause real (inflation-adjusted) prices to rise by only about 1% a year. Even fairly pessimistic assumptions about the quantity and quality of new coal reserves push the expected price escalation only into the range of 1.5–2.0% a year.

This scenario could change drastically, however, if acid deposition legislation suddenly increased the demand for low-sulfur coal. For example, Alan Cope of Consolidation Coal Co. examined the effect on premium coal of proposed legislation (the so-called Mitchell bill) to reduce sulfur dioxide emissions by eight million tons a year by 1993. He concluded that coal production in eastern Kentucky and in Colorado and Utah could potentially triple if the local mining and transportation infrastructure could stand the strain.

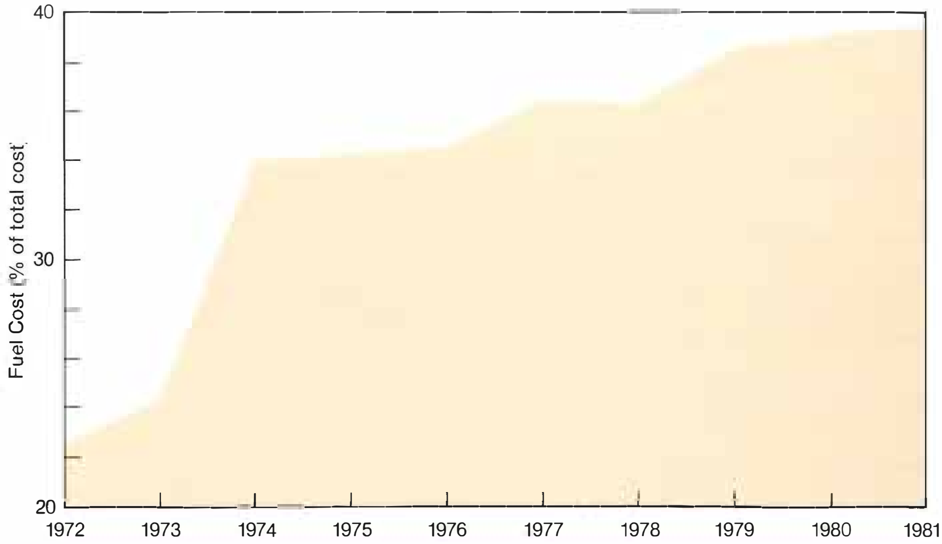
Unfortunately, Cope thinks it cannot. "What is more likely is that the demand pressure will force up sulfur premiums to the point at which more utilities will decide to scrub higher-sulfur coal, and export demand [for low-sulfur coal] may be lost to other countries. Already," he says, "some foreign buyers are protecting themselves by making equity investments in coal mines in the United States and other countries."

According to a recent Edison Electric Institute survey, many utilities anticipate that there will be no low-cost way to reduce emissions to satisfy the requirements of the Mitchell bill. Fuel switching plays an important role, but the largest number of responses (in terms of generating capacity represented) reported plans to scrub higher-sulfur coals. Although the recourse to scrubbing could change at lesser levels of required emission reductions, the response most forcefully illustrates the uncertain outlook for coal prices. These range upward from modest to very high levels.

The outlook for residual oil and natural gas is even more clouded because of uncertainties over the amount of reserves that are available and uncertainties in the future demand for natural gas by nonutility users. George Hall and William Hughes of Charles River Associates, Inc.,

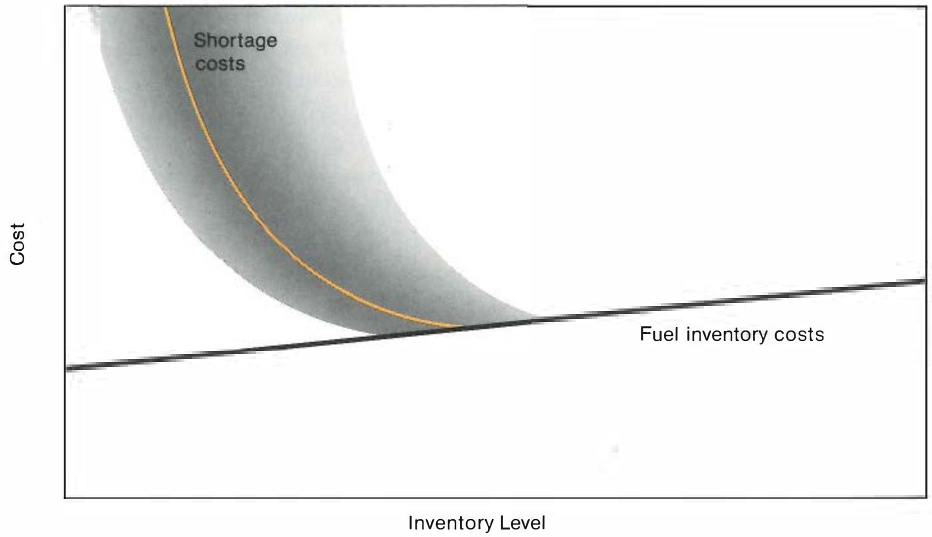
The Rising Importance of Fuel Costs

The cost of fuel has become an increasingly large component of the overall cost of producing electricity. Between 1972 and 1981 the fuel cost figures for investor-owned utilities jumped dramatically from 22.5% of total cost to over 39%.



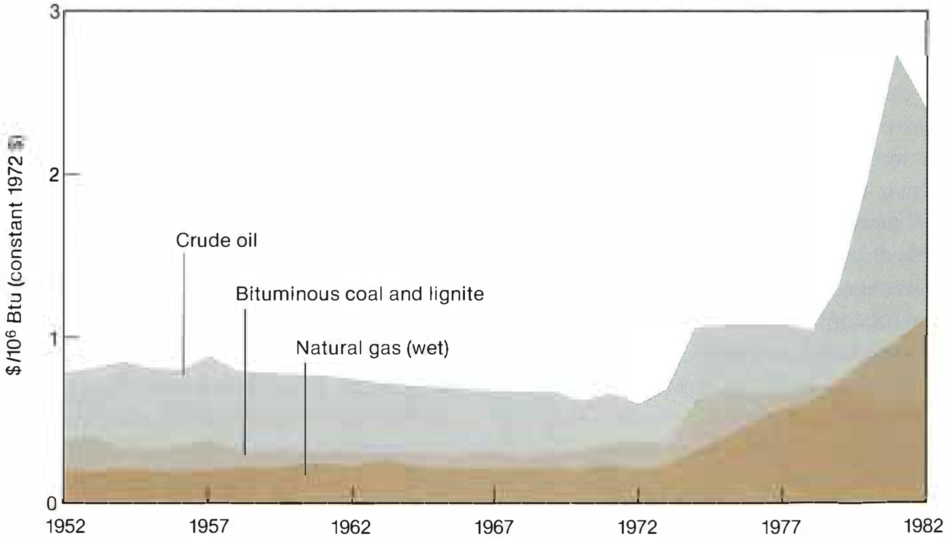
Trade-offs in Inventory Planning

Planning fuel inventory levels involves weighing the costs of increasing fuel inventories beyond expected demand against the costs of not having enough fuel available when it is needed. Because shortages are addressed by options that have high cost variability, such as purchasing fuel on the spot market or buying power from a neighboring utility, there is generally a wide envelope of uncertainty surrounding the shortage cost curve.



Fossil Fuel Prices

The prices of domestically produced fossil fuels were shaken out of a steady historical groove in the early 1970s by worldwide oil prices and resultant changes in global economics. The relative unpredictability of prices over the last decade has made the fuel planner's job considerably more challenging.



say that although gas supplies are highly uncertain, there is likely to be enough available for utilities to take advantage of at least some opportunities to trade off gas against oil. And Thomas Manning of Pace Co. says that residual fuel oil will remain in surplus beyond 1990 because many present refineries cannot convert it to lighter products and because crude oil available to refineries is becoming increasingly heavy. "Such fuel oil surpluses," he asserts, "will keep the lid on the price of natural gas if it is to compete with residual oil in the industrial and utility boiler fuel markets."

But others take far more pessimistic viewpoints. Consulting geologist Arthur Warner believes that the rate of finding new oil and gas for a given amount of drilling will continue to decline, leading to progressively higher costs for new reserves of both oil and gas. "In particular," he says, "exploration in the conterminous 48 states is now like milking an old cow." Most important, Warner concludes that valuable time has been lost because the country has failed to recognize the comprehensive value of developing other domestic energy alternatives, such as coal and uranium.

The Gas Research Institute points out another aspect of this argument, maintaining that the availability of gas supplies depends in part on technology development. "We could extend the adequacy of lower-48 supply another 5 to 10 years at what we believe will be acceptable prices if the new tight gas formation technologies GRI is helping to develop prove to be commercially successful," comments Henry R. Linden, GRI president. "But unless the outlook for world oil prices and industrial and power plant use of coal changes markedly, we will have ever-increasing difficulties in competing for the boiler fuel market."

Meanwhile, uranium is available in such oversupply that prices are severely depressed and higher-cost mines and mills are being closed. According to Michael Connor of Nuclear Resources International, the oversupply is particularly acute outside the United States and producers in other countries have increased sales efforts in this country. However, in the long term, prices will begin to increase again, particularly if proposed federal legislation curtails uranium imports.

Taking a regional approach

Such insights into broad fuel supply trends can help utilities better understand and cope with the impact of global events on regional fuel markets. A variety of local considerations, however, may have more immediate impact. These include what type of power generation facilities predominate in a region, whether they have the flexibility to use more than one kind of fuel, what fuel alternatives are available, how much it costs to transport the different fuels, how rapidly electricity demand and generating capacity are growing, and whether purchased power is a viable option.

To help shed more light on these issues, EPRI has launched a new series of regional studies focusing on local utility fuel markets and interfuel relationships. The first of these studies, prepared by Charles River and concentrating on the Gulf and Southeast region, has just been published. Two others, related to the Northeast and California, are now in progress.

The Gulf states analysis illustrates how seemingly abstract fuel supply trends can suddenly take on immense practical significance and underscores the importance of regional differences in regional markets for utility fuels. In particular, the study concludes that supply uncertainties are forcing utilities to adopt more sophisticated purchasing and inventory strategies, which may eventually lead to wide, rapid swings in fuel use and the emergence of an active futures market for boiler fuels.

The region in question—stretching from Texas to Florida and including the adjacent states of Oklahoma and Arkansas—has some unique fuel supply characteristics. It is the largest natural gas–consuming area in the United States, but it also includes some large coal-fired systems and several Florida utilities that are shifting from strong dependence on residual oil to more diversified patterns of fuel use.

Throughout the region, coal has become the dominant baseload fossil fuel for new generating units. Roughly speaking, it costs about $5 to produce a million Btu of heat from oil and gas purchased in the region but only about $2 per million Btu for coal. And coal is likely to retain its baseload competitive edge even if its cost rises substantially and interest rates remain high.

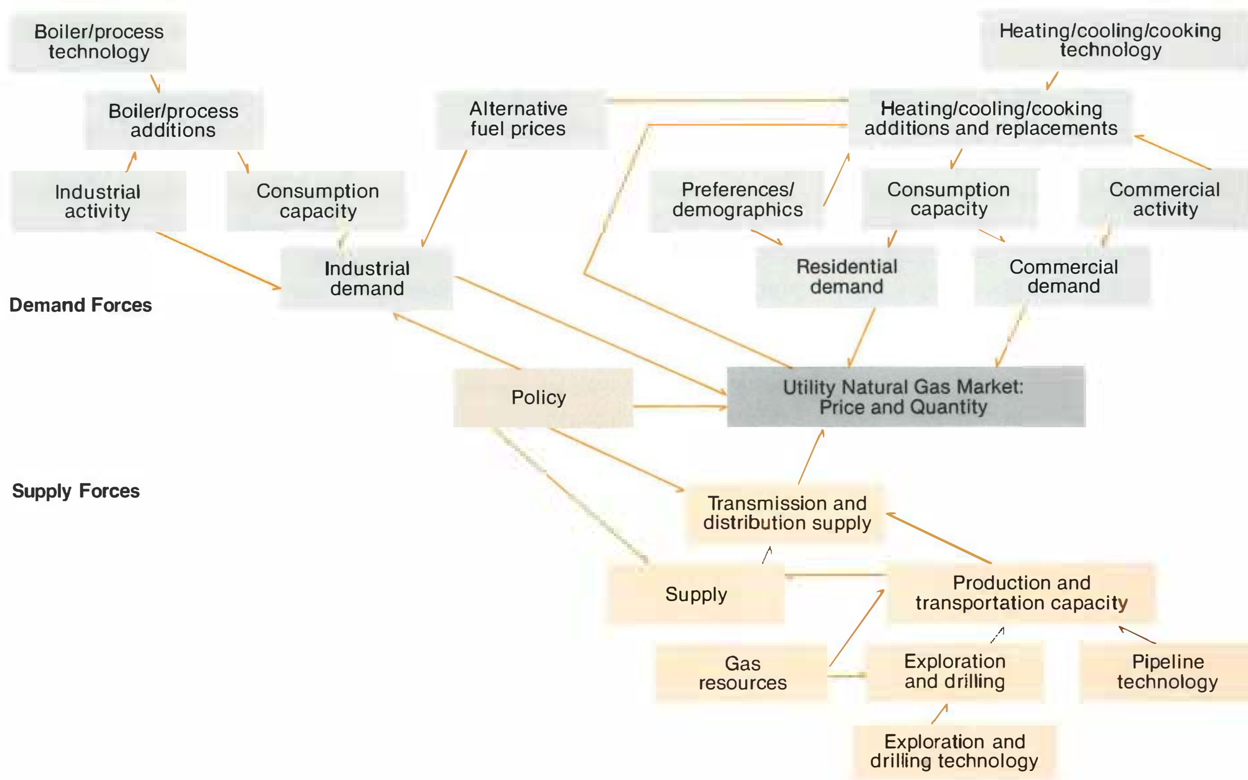
Coal-fired plants are much more expensive to build than those burning oil and gas, but over the lifetime of a plant the higher costs of the other two fuels more than compensate for the capital cost savings. For high-cost capital (charges of about 18% a year), coal prices would have to increase about 50% for new power plants using oil or gas to be competitive in the region. And if interest rates come down (say, enough to produce annual capital charges of 12%), the price of coal would have to double for it to lose its competitive edge.

Further penetration of coal into the fuel mix is generally limited to new plants, however, because almost none of the region's older oil- or gas-fired units are now scheduled for replacement. Also, about one-third of these older units are able to burn either oil or gas, and more could be converted to dual fuel capability if there is sufficient incentive to do so. As a result, a lively competition is developing between oil and gas as boiler fuels in the Gulf region.

Utility demand for oil and gas can change rapidly. These are marginal fuels in the sense that short-term growth in electricity use is more likely to be met by using existing oil- or gas-fired plants than by adding new coal-fired baseload plants. Because just a 5% increase in the demand for electric power can result in a 25% increase in the demand for fuel oil and natural gas, utilities can profit

Understanding Fuel Markets

In general terms the utility natural gas market is simply a function of supply and demand. But the complex networks of interactive forces that drive supply and demand make planning for even this one fuel market an extremely difficult prospect.



substantially by taking advantage of interfuel competition.

Such competition is likely to continue in the region for at least the rest of this decade, according to Charles River. "In the absence of a major crisis leading to crude oil shortages," the report concludes, "there is likely to remain an overabundance of residual oil, causing its price to stay $6–$7 below the price of crude." Further, the price of residual oil should provide a cap for natural gas prices. As recent legislation gradually deregulates the price of natural gas at the wellhead, market forces are expected to determine its price according to competition with residual oil, once transportation costs have been taken into account.

In turn, the abundance or scarcity of natural gas will determine just how far from the gas-producing areas oil and gas markets will interact. If it is abundant, gas may be able to compete as far away as the Middle Atlantic states. If scarce, its use as a utility fuel may be confined to the core producing states of Texas, Oklahoma, and Louisiana. Gas availability will also affect the price differential between crude and residual oil, with abundant gas lowering the relative value of residual oil.

Trading different fuels off against each other will require more flexible contracts between utilities and suppliers. Such contracts already include a variety of cancellation and extension options to cover contingencies of changing markets, and a wider mix of long- and short-term contracts is becoming common. Gas deregulation is expected to lead toward a spot market for gas, which utilities could use whenever prices are advantageous. And the emergence of a futures market for residual oil and gas may eventually let utilities hedge against the future in the same way major purchasers of other commodities do.

Better tools needed

To face these challenges, utilities are having to adopt more-complex fuel-use strategies. These, in turn, require the development of better analytic methods. "A couple of decades ago, all you needed to do fuel planning was semilog paper and a straightedge," says Grundmann. "Now you have to make these decisions in circumstances of uncertainty, and therefore your decision-making process has to be much more complex—you have to use much more sophisticated tools. And documentation is vital—because of the propensity to review decisions, you have to be prepared to defend them at any time, even 15 years after you've made them."

Consolidated Edison's Bell emphasizes the need to take more factors into account. "We need to know more about interfuel competition. As an example, we should have a better handle on the availability and pricing of natural gas supplies because of the interrelationship between natural gas and residual oil. If gas is available at the right price, it means utilities use less imported oil. On the other hand, is it really in our national interest to use a precious fuel like natural gas in a boiler? We need better ways to put some numbers on these questions—tools that allow us to frame the questions in more quantitative terms."

In response to these changing needs, the Energy Resources Program is shifting its research emphasis in several important areas. This shift reflects priorities developed in coordination with the fuels committees of the industry trade associations and individual utility fuel planners.

Coal research will concentrate more on utilization strategies that can help utilities cope with demand growth and proposed acidic deposition legislation. A particular effort will be made to increase the understanding of the possible fuel market impact of such legislation. Most gas supply research related to the outlook for prices and availability will be completed by the end of this year, concluding with studies of physical constraints and market issues. Several new fuel transportation issues will be addressed.

One new research activity initiated this year is aimed at helping utilities integrate their fuel and investment decisions. The objective of this project is to provide the analytic methodologies and information needed to take a full-system cost approach toward evaluating major fuel and hardware choices, especially those related to sulfur reduction under proposed acidic deposition legislation.

Other ongoing projects related to fuel planning include inventory modeling, fuel use forecasting, development of methods for evaluating alternative fuel

A CASE STUDY: FUELS FOR FUEL CELLS

Beyond providing improved analytic tools and better fuel market information for utilities to use in fuel planning, EPRI is conducting a few studies to produce new information on fuel supply in areas of particular concern. Usually such studies are undertaken in response to a specific request from a utility industry group. A recent example is an analysis of potential fuels for fuel cells. This study's conclusions were incorporated into a report by the Fuels and Fuel Processing Subcommittee of the Fuel Cell Users Group.

The study was conducted by National Economic Research Associates, Inc., which determined the outlook for the availability and price of six potential fuels for use in fuel cells through the year 2000: oil, naphtha, propane, methanol, ethanol, and natural gas. (Besides its high thermodynamic efficiency, one of the most attractive advantages of fuel cell technology is its ability to accept a wide range of fuels.)

One of the major conclusions of the study was that a basic shift in relative fuel economics for fuel cell fuels is likely to take place by the turn of the century. Now, at a cost of about $2.62 per million Btu, natural gas is the most cost-effective fuel for fuel cells. However, the real (inflation-adjusted) price of natural gas is expected to more than double by the year 2000, reaching about $5.50 in constant 1983 dollars.

By that time, the most cost-effective fuel will probably be propane, which is expected to be priced in the $5.00–$5.50 per million Btu range. Propane and other liquefied petroleum gases are by-products of natural gas production and crude oil refining, and increased capacity to produce them abroad is likely to keep their real price about constant for many years. Their availability, however, may be subject to the same uncertainties as imported oil. Recently, propane sold for about $5.00 per million Btu, on the average. The price crossover between natural gas and propane should occur sometime in the 1990s.

The next two most attractive candidates from a cost perspective are No. 2 fuel oil and naphtha, with prices for both expected to remain in roughly the $6–$7 range. Methanol produced from natural gas is expected to be abundant but rather expensive (more than $10 per million Btu) because of its use as in industrial feedstock. Ethanol, produced from petroleum, is also used as an industrial chemical and should run about $23–$25 per million Btu.

These price and availability relationships are important to utilities as they approach commercial adoption of the fuel cell and underscore the desirability of fuel flexibility for the fuel cell technology. □

procurement strategies, and provision of guidelines for fuel contracts. In some of these projects, staff from the Decisions Methods and Analysis Group in EPRI's Economic Environment Integration Program comanage projects and contribute their expertise in decision analysis and operations research.

Inventory planning

One of the key ways utilities have of matching fuel needs to availability is inventory management. Fuel inventories make it possible to carry on power generation with relative independence from daily fuel supply conditions. They also reduce costs that increase with frequent purchases and provide a hedge against shortages resulting from uncertainties in either fuel supply or electricity demand. In addition, adequate inventories allow utilities to smooth out the fuel supply variations associated with seasonal demand and irregular delivery schedules.

To manage inventories and minimize costs, fuel managers can manipulate the timing and quantity of deliveries, make purchases on the spot market, and sometimes adjust generation dispatch. Traditionally, inventory management has been based on experience and judgment. Only a few utilities now employ formal models to examine the trade-offs between the costs of holding inventory and the costs of inventory shortages. However, the informal approach is starting to be questioned by both utilities and regulatory commissions.

In Florida, for example, the Public Service Commission recently encouraged the state's utilities to take a more quantitative approach. "They developed a generic inventory policy, which they propose to use for ratemaking purposes when a utility fails to justify an alternative inventory policy within 12 months from the order," explains Ross Baldwin, fuel coordinator of Tampa Electric Co. "A utility either has to use that generic policy or come up with an alternative inventory model that quantifies some other level of inventory. We have to be able to justify both the alternative model and the inventory to the commission."

Such quantification is difficult because of the uncertainties that must be taken into account. EPRI work, however, has already provided some useful insights into the problem, and a new project has been launched to develop a broadly applicable inventory modeling systems for utility fuels.

One important insight developed so far concerns trade-offs implicit in fuel inventory management. The trade-offs involve two costs—the cost of carrying the inventory (holding costs) and the expected shortage cost associated with reducing burn at a plant because of too little fuel. As fuel stocks grow, holding costs rise slowly and are proportional to inventory size. By contrast, as a utility attempts to increase efficiencies by reducing inventories, a point is reached where shortages become likely, and expected shortage costs begin to rise dramatically. Adding these two costs at various inventory levels produces a U-shaped curve with a minimum at the point where the probability of having shortages approaches zero.

Defining the inventory levels at which shortages are likely to occur is a key problem faced by individual utilities. Currently, information about where this level occurs is very limited; most utilities have not yet experienced inventory shortages, and there have been few attempts to build models that help quantify the critical region. Although utilities are under increasing pressure to reduce inventory levels, it is risky to fine-tune inventory levels to keep holding costs low for the short term without a quantitative understanding of the trade-offs. In the longer term, inventory management should allow for a reasonable range of inventory levels that balances holding costs and expected shortage costs instead of focusing on precise least-cost inventory levels. The objective of EPRI's inventory research is to develop tools that utilities can use to gain such quantitative understanding.

Coordinating industry effort

Because so many utilities are now so deeply affected by rising fuel costs, much of the fuel supply research being conducted by EPRI would have to take place anyway, but it would be scattered among various industry groups. EPRI is thus providing a critical element of research coordination among an increasing number of utility participants. "The important point is that this is work utilities would be doing individually and paying for over and over again," comments Grundmann. "Through EPRI, they are getting this type of research in a more highly centralized manner, and they're getting a lot higher-quality work and a lot better return on their research investment. A lot of EPRI's hardware programs are longer in range, but this sort of software research is immediately transferable and usable by the utilities."

Bell expresses a similar thought. "It's important to understand that although these programs are not that expensive, the payoff and the insights they provide are very substantial. These models find their path to utilities very, very quickly and are put to use in a very timely way."

Fuel supply research being conducted by EPRI is thus providing the electric power industry with a coordinated, timely response to a growing problem. From this research, utilities can gain both new information about fuel markets and new methods for analyzing their own fuel needs. Reports from utilities now taking advantage of this research indicate that its benefits are very large, compared with its cost. ■

Further reading

Regional Electric Utility Fuel Markets. Prepard by Charles River Associates, Inc., for RP1981-10, August 1983. EPRI EA-3210.

Proceedings: Fuel Supply Seminars. Prepared by Atlantis, Inc., for RP1981-11, March 1983. EPRI EA-2994.

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This article was written by John Douglas, science writer. Technical background information was provided by Eugene Oatman, Stephen Chapel, Howard Mueller, and Jeremy Platt, Energy Analysis and Environment Division.

Quick Response to Stack Gas Queries

A growing number of utilities are calling the QRI experts for technical answers to their emission control problems.

Many utilities think of EPRI as being concerned primarily with big-picture issues, such as technology development, system reliability, and environmental protection. But member utilities often need help finding answers to tough, day-to-day technical questions: How can condensation be prevented in flue gas scrubber outlet ducts? What processes are available for combined removal of SO_x and NO_x from combustion gases? Which computer model will best estimate pollutant concentrations near a given power plant? When the technical stumpers relate to stack gas control technology, EPRI provides a formal way to get authoritative answers quickly, enabling utilities to pare down operation and maintenance costs of these systems with minimum effort.

Appropriately called the quick-response inquiry (QRI) service, this project is administered for EPRI by the Stack Gas Emission Control Center at Battelle, Columbus Laboratories. An average of six to eight inquiries a month are received at the center, usually involving questions about scrubbers, NO_x control, coal cleaning, and particulates. According to the ground rules, each inquiry is expected to take less than one man-week of effort to answer. The service is free to EPRI member utilities; it is also available to EPRI project managers and to the industry's trade associations.

With some additional support from other organizations, EPRI established the center in 1974 to collect and analyze data on current experience with stack gas control technology. Each year specialists from the center visit about eight fossil fuel power plants with various types of emission controls and write site reports based on their observations. The reports are published as part of the center's bimonthly status report, which also includes copies of QRI responses for the period and reprints of pertinent publications and abstracts. The center's staff also periodically surveys all operating flue gas desulfurization (FGD) systems on utility boilers in the United States and similar systems on coal-fired plants around the world.

When a QRI reaches the center's Inquiries Office, it is assigned to either a QRI specialist or some other member of Battelle's technical staff. After approval by the QRI manager, the staff researcher prepares a response based on information in the center's own data base, in EPRI reports, or, perhaps, in some external technical library. Occasionally, questions are referred to outside consultants. A typical QRI may be as simple as a request for recent technical documents or a copy of the latest trip report on an operating scrubber. Sometimes it may entail an in-depth literature search on a special topic.

The topics involved in QRIs cover the full range of technical issues in stack gas control, from FGD slurry pump servicing to baghouse operations, coal-cleaning processes, and choice of scrubber packing materials. The types of inquiries generally fall into one of two broad categories, explains Stuart Dalton, EPRI's program manager for desulfurization processes. The first involves difficult design and technology choices related to standard plant decisions, such as materials selection for FGD systems or comparison of the costs and benefits of different control processes. The second category is a potpourri of unusual, one-of-a-kind problems. "For the first type of inquiry there is a huge body of information available in which to look for answers," says Dalton, "and the challenge is to find the right information. But for the second type, there may be no information in the literature, so some detective work is required to solve the problem."

In an example of the first type of problem, Monongahela Power Co. faced a materials dilemma at its Pleasants power station in repairing a stack damaged by acids that condensed after the unit's scrubber. The question was whether to replace the stack entirely, using higher-grade materials, or to apply a new stack lining that would prevent further corrosion. Cost-benefit data and utility experience reports from EPRI's QRI service allowed utility managers to confidently choose a relatively inexpensive coating for the existing unit that could be routinely maintained for its remaining life. This choice averted the cost of a new stack and the substantial downtime that would have been required for complete replacement. Also, in subsequent planning for a new unit it was bringing on line, Monongahela consulted the QRI data and specified acid-resistant brick as the best choice for the unit's new stack.

Long Island Lighting Co.'s Northport station provides a good example of a one-of-a-kind problem. Complaints there about ambient sulfur odors threatened to jeopardize Lilco's state exemption to burn high-sulfur fuel oil in three 375-MW boilers. The fuel arrangement saves tens of millions of dollars a year, but complaints about sulfur odors raised suspicions that SO_2 emissions were exceeding limits, so the plant could have been forced to switch to more-expensive low-sulfur fuel. With the help of QRI staff, however, Lilco was able to determine that the offending odor originated not from stack SO_2 but from intermittent formation of H_2S or COS, which have a detectable odor in concentrations a thousand times lower than SO_2. The problem was remedied, state regulators were reassured, and Lilco's fuel savings remained intact. The company estimates it will save approximately $260,000 in revenue requirements, thanks to the support of QRI staff.

Feedback from the QRI service can be useful in helping EPRI respond to utility needs in more general ways, according to Charles Dene, the project manager. "We use these inquiries to tell what problems utilities are having with stack gas equipment," he says. "If we get a lot of QRIs on a subject, it will likely be considered as a candidate for future research. For example, when a lot of questions came in regarding operation and maintenance costs of different scrubbers, we initiated a project to compare costs at utilities across the country."

Similarly, a rash of QRI calls kicked off a new EPRI project to come up with an efficient way to measure the effectiveness of mist eliminators. Dene explains, "A lot of utilities put in their specs that the mist eliminators must be of a certain efficiency, but when the units were installed, it turned out nobody had a good way to demonstrate that the equipment was really doing the job. There's very little information available and lots of questions on how to make such measurements. The QRI inquiries alerted us to the need for research in this area."

Utility response to the QRI service has been very supportive. According to Dene, utilities that have used it once tend to come back again, and when a questionnaire was sent to past users, asking if the information provided had been helpful, the replies were overwhelming: "The response was positive in almost every case."

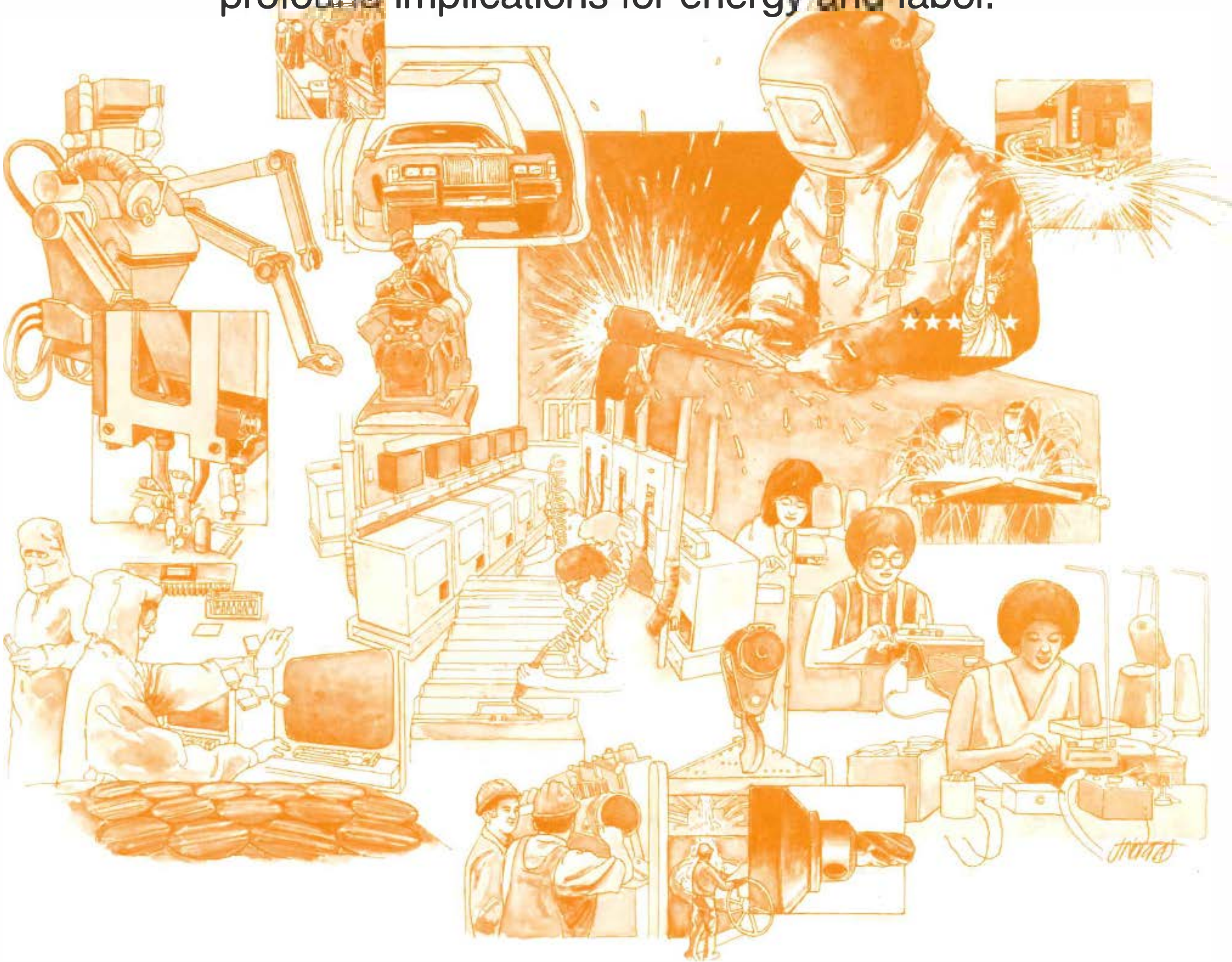
EPRI member utilities may contact the QRI center at Battelle-Columbus directly by telephoning (614) 424-7885. Further information on the service is available from EPRI Project Manager Charles Dene, (415) 855-2425. ■

This article was written by John Douglas, science writer. Technical information was provided by Stuart Dalton and Charles Dene, Coal Combustion Systems Division.

ENERGIZING AMERICAN INDUSTRY FOR GLOBAL COMPETITION

by Brent Barker

A meeting of EPRI's Advisory Council and guests from basic industries provided a lively forum on transition in American manufacturing. The worldwide automation imperative has profound implications for energy and labor.



Paris wasn't the only draw for the WWI doughboys. Coming home, they found the tempo of transition from farm to factory quickening. Machines of every shape and function were taking to the fields and highways, releasing farm labor to other parts of the economy and releasing industry from its tether to railroad sidings and harbors. Manufacturing sped toward automation, freed in part by the electric motor toward entirely new forms of productive logic. And mass production put appliances into homes and offices, turning labor toward more profitable pursuits. Overall, it was a decade in which growth in industrial productivity soared to its greatest heights in the twentieth century and in which energy in its newest and most highly flexible forms—fluid fuels and electricity—played a major catalytic role in the expansion.

Fifty years later the great economic engine appears to have stalled. Productivity growth (to which economists attribute as much as 75% of the growth in GNP) has reached its lowest point in the twentieth century. Basic industries from steel to autos are in disarray. Electricity consumption is flat. U.S. industry from smokestack to high tech is facing fierce competition from around the globe. And unemployment at unprecedented high levels appears to be an entrenched part of the U.S. economy. It was this confluence of disturbing issues that drew together the 60 participants at the EPRI Advisory Council's annual seminar to discuss the topic The Prospects for Revitalizing American Economic Growth and Its Implications for Energy Consumption Patterns. At the Hotel Del Coronado in San Diego, twelve speakers and panelists from manufacturing, services, universities, utilities, and EPRI sparked the three days of discussion among the Advisory Council, itself representing diverse views of leaders from business, labor, universities, environment, and public utility commissions.

Each day from three to five speakers addressed the assembled group before the floor was finally opened to pent-up commentary, questions, and freewheeling discussion. Open-ended and sometimes erratic, the exchange moved in and out of dozens of interlocking technical, economic, and social issues facing American industry. Energy was one common thread; it both opened and closed the meeting. Another was the productivity of our basic industries. But emerging perhaps as the central theme to which speakers and participants continually returned was the new reality of international economic competition.

Global competition

Overall, there was an urgent sense that the United States is still holding fast to its notion of a closed economy; that despite the growth in international trade from 10% to more than 25% of U.S. GNP in just two decades, the nation is still not sufficiently aware of its growing participation in and susceptibility to global competition.

Where the United States has moved fast, as in computers, it has retained its technical and market dominance. But elsewhere, import penetration has been rapid: between 1970 and 1982 imports of consumer electronics have risen from 30% to nearly 60%, autos from less than 10% to more than 30%, steel and machine tools from around 15% to more than 25%.

Technology has to a large extent become a ubiquitous worldwide commodity, and the United States will not necessarily determine the pace of future development and use. By one estimate at the meeting, there will be about a million advanced robots in the world by 1990, but only about 10% will be in the United States. The portent is that technical change will accelerate, emanating from many points on the globe, and market competition will intensify, particularly during times of global recession when nations grapple for contracting markets.

Commenting on the worldwide rush for comparative advantage, Henry Singer quoted James Baker, executive vice president of General Electric Co., when he said, "Industry has three choices: automate, emigrate, or evaporate." Rising to the challenge, Chauncey Starr, EPRI's vice chairman, declared, "The issue is whether American industry has the freedom, flexibility, and incentives to restructure itself to use advanced technology. Given the freedom to do it, this country can do it. Capital is not the issue. Organization is the issue." And Alvin Weinberg, director of the Institute for Energy Analysis, Oak Ridge Associated Universities, added another key element to resurgence when he said, "The United States has a structure and spirit of entrepreneurship that doesn't exist in other countries," a spirit that Walter Marshall, chairman of England's Central Electricity Generating Board, said "existed in our country during the Victorian Era."

Pat Choate, senior policy analyst for TRW, Inc., indicated that some awakening to international competition is occurring and industrial policy could well become the dominant issue in Washington in 1984. "There is growing realization," he added, "that the cumulative effect of government interventions in the United States has been to stretch out business decisions by many years, thereby dulling the U.S. competitive edge."

Threat to the underpinning

Serious concerns were raised about the direction of U.S. manufacturing in the face of global competition. Its diminished role in the U.S. economy—now accounting for only about 20% of the work force and 30% of the GNP—seems to belie its central importance. Manufacturing remains the critical underpinning of the vast service industries, and as such, its vulnerability to international competition appears to lay open a much larger and broader threat to the economic health of the nation than to manufacturing alone.

Manufacturing, at least in aggregate, is not so much in decline as overwhelmed by the flourishing service sector. Manufacturing employment actually increased by several million workers over the last two decades, but the preponderant growth has been in the linked service industries—finance, utilities, transportation,

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Pat Choate
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James Cook
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communication, wholesale and retail trade, government, and producer and business services. Of the 25 million new jobs created since 1970, about 90% have been in these service areas. But as several speakers pointed out, notably Sam Schurr, deputy director of EPRI's Energy Study Center, and Richard Zeren, director of EPRI's Planning and Evaluation Division, the historical shift from manufacturing to services has been much greater and faster in terms of employment than in dollar output. Even in such so-called declining industries as railroads and textiles, output has increased rapidly, while employment has fallen off. Productivity improvements in manufacturing have helped to maintain the value added (increment of value added to a product during processing), while workers have been released to other sectors of the economy.

"In truth," said Pat Choate, "manufacturing is going the way of agriculture, that is, fewer workers, higher productivity, and improved quality. If anything we should accelerate this process because the rate at which we accelerate it will determine our competitiveness. . . . The United States cannot afford to concede its basic industries and the value added they provide. This value added is the foundation for the service industries that in turn provide substitute employment for manufacturing." His suggestion that the United States hold on to its manufacturing base and build on it just as assuredly as it did with its agricultural base was supported by another participant who pointed out that "in the United States 2.4 million farmers produce nearly three times as much as our 7 million farmers did 50 years ago."

Smokestack versus high tech

In discussing the direction of U.S. manufacturing, attendees drew a sharp distinction between the older, more mature industries producing such basics as steel, chemicals, paper, autos, and housing and the newly emerging industries of electronics, instruments, biotechnology, and the like. These took on the shorthand of smokestack versus high tech. High tech was widely assumed to be the booming growth area, but more as an adjunct than as a substitute for the smokestack industries. One reason clouding the prospect for outright substitution in the United States is that high tech is the battleground of the future as nation after nation targets such fields as computers, robotics, genetic engineering, and nuclear power as its springboard to prosperity.

Concern for the smokestack industries centered on whether they were in a period of temporary depression or permanent decline; whether they could be rejuvenated by an infusion of capital, or by technical innovation, or by a loosening of U.S. monetary policy; and whether they were a necessary ingredient for national security. Recalling the reign of OPEC, Floyd Lewis, chairman of the board and president, Middle South Utilities, Inc., begged the question by asking, "Do we want to put ourselves at risk by becoming dependent on other nations for our basics?"

The nature of decline in basic industries was given a unique perceptual twist by James Cook, author of "The Molting of America" and executive editor of Forbes, Inc., who used the term *downsizing* to describe his sense of a fundamental evolution occurring in U.S. manufacturing. "You use less of everything—labor and materials, first and foremost—but also manufacturing itself because of the simplification of design." His examples ranged from smokestack to high tech and focused on autos (what one panelist called the incredible shrinking car) and electronics. "In the mid 1970s," Cook said, "Congress mandated fuel economy standards that would bring about a 50% reduction in fuel consumption by 1985. At the time hardly anybody realized the implications, but the consequence was probably a permanent downsizing of a good portion of the U.S. manufacturing economy. The auto industry began sloughing off weight and wound up downsizing a good portion of the industrial base that

Pat Choate

"Manufacturing is going the way of agriculture, that is, fewer workers, higher productivity, and improved quality."

Richard Zeren

"In many so-called declining industries, the shift has been primarily in terms of employment rather than output."

James Cook

"The auto industry began sloughing off weight and wound up downsizing a good portion of the industrial base that supported it."

Elizabeth Bossong

"The cost of capital . . . has reduced our ability to put in the kind of plant and equipment that would increase our competitive posture in the world."

supported it, from iron and steel to glass and textiles to auto parts and machine tools. . . . And with smaller cars, the market was effectively internationalized."

With electronics, downsizing has been even more dramatic. "The first computer cost $3 million, occupied a space as large as a freight car, and used so much electricity the lights of Philadelphia are said to have dimmed every time it was turned on. A comparable machine today is not much larger than a typewriter and weighs 300 pounds. . . . Semiconductors provide a similar model. Tons are reduced to pounds, pounds to ounces. Unit costs are reduced. A few dozen microprocessors can replace 80 pounds of switches in a vending machine. One microprocessor replaces 350 parts in a sewing machine."

Several panelists viewed the fundamental situation facing basic industry less in terms of evolutionary forces, such as downsizing, than in terms of a weakened economy and misguided federal policy. Gus Tyler, assistant president of the International Ladies Garment Workers Union, said, "One of the factors facing the United States in the 1970s was a government decision to restrain growth. And with the assistance of the Federal Reserve Board and its tight monetary policies, they succeeded. . . . The 1980 campaign suggested another way out: enlarge growth by putting more money in the hands of the investing classes. But capital is not yet flowing. Business will tell you 'Why invest in new plant and equipment when we are still operating at only 70% capacity; we are waiting for a consumer-led recovery.' But after 10 years of demand management, of stifling growth, how can we expect the consumer to lead?"

Elizabeth Bossong, manager of economic research for U.S. Steel Corp., also assailed the conduct of the monetarists for suppressing growth in the capital goods industries by keeping interest rates high. "We're now operating in an economy without precedent. The impact of tight money since this program of monetarism began in the fall of 1979 has been to drive up the price of capital and to overvalue the dollar by 25%. The cost of capital has increased to a level devastating to basic investment. It has reduced our ability to put in the kind of plant and equipment that would increase our competitive posture in the world. It is sucking in hot money for short-term investment. And it is driving long-term investment overseas. The overvalued dollar can now buy up facilities on the cheap worldwide, locking in a still longer term disadvantage by driving future job creation abroad."

The automation imperative

When the United States operated as a closed economy, it could afford to commercialize technical innovations at a slower pace. But now that it is faced with intense global competition, the acceleration of cost-cutting innovations has become imperative. Much of this in manufacturing discrete products translates into automation—making materials and work pieces flow through in less time, producing more with fewer machines, upgrading quality, and minimizing inventory. "Automation," said Henry Singer, vice president of the Industrial Sales Division, General Electric Co., "used to be the work of efficiency experts, time and motion specialists, and industrial engineers. Now it's getting the attention of top management because it's the only game in town. The worldwide competitive arena is real, and it has placed unrelenting pressure on price. The only thing left is to cut costs or watch profits erode."

Significant opportunities for automation abound. Pat Choate estimated that one-half of all manufacturing jobs in the United States can be replaced with existing automation technology. Henry Singer pointed out that because 90% of an assembly machine's time is typically idle, productivity gains in capital equipment are potentially enormous. And James Cook envisioned electronics as America's new core industry, with the capability for infusing everything—products and processes alike—in the scramble to cut costs and boost productivity.

Examples of recent automation advances cited at the meeting reveal automation's potential impact on manufacturing. General Electric's plant in Louisville, Kentucky, for example, will soon be turning out dishwashers on a fully automated basis, stretching from computerized design and manufacturing to computerized marketing and distribution; the company expects to eventually replace half of its 37,000 appliance assembly workers with robots. Western Electric Co., Inc., has committed its operations to electronics and reduced its labor force from 200,000 to 145,000. Hughes Aircraft Co. has put in a flexible system in one plant, cutting costs by 90%. But the most dramatic examples throughout the discussion always seemed to fall to Japan. Henry Singer reported, "Yamasaki's Mayzak Division has stirred imaginations worldwide by making parts for their machine tool operations with a factory that is completely flexible. They have cut floor space in half, reduced machines needed from 68 to 18, slashed in-process time from 90 days to 3, and reduced labor by a factor of 7 to 1."

The situation facing U.S. manufacturing is no longer whether to automate or not—for competitive survival has foreclosed that choice—but rather how to marshall the considerable resources of the nation to meet the challenge. Technical and creative skills are not enough. Capital must be made available at reasonable cost, technical innovations sped into productive use, the human resources of the work place refocused and reorganized, management receptivity to risk improved, and clear incentives established.

Historically, technical innovation during 1948–1966 accounted for 40% of productivity growth in the United States, according to Sam Schurr, and the substitution of capital for labor—the so-called deepening of capital—for another 20%. Implied in the comments of other participants was the notion that today's slump in productivity may be less the result of a slowdown in U.S. innovation than a slowdown in the rate of adoption of new technology. Some nations facing this same problem have sought solution through public policy. Japan, for example, gives an extra 13% investment tax credit for investment in robots and has created a leasing company to help small firms robotize. This will help them speed the process of automation by cutting the risks associated with first and second generations of technology.

Regarding the flow of capital, Pat Choate offered some insight when he said that a considerable portion of U.S. capital is now being diverted to nonproductive investments to meet social objectives and accommodate regulatory delay. Although capital investment remains roughly at its historical level of 10% of GNP, he estimates that 2–3% is now going to finance delay.

The displaced worker

Looming as perhaps the largest social issue of the inevitable rush to automation is the plight of the displaced factory worker and the coming political ramifications of massive structural unemployment. From two to four million are said to be permanently displaced, and unemployment benefits, one measure of the inability to get people back to work, reached over $30 billion last year. With millions more facing the specter of robotized replacement in the coming decades, Pat Choate for one sees the possibility of "the rise of a neo-Luddite movement. There are already growing demands for protectionism, and plant-closing legislation has now been introduced in 26 states."

Worker displacement is hardly a new problem, and historically it has tended to be largely self-correcting; technologic change in the United States has in the end produced more jobs than it eliminated. The service industries have traditionally absorbed most of the displaced labor. But this time the dimensions of the problem may exceed historical precedent, especially when coupled with growing expectations by workers for job security. Among some participants there was the sense of a gathering storm. "The uncomfortable

Henry Singer

"Automation . . . is now getting the attention of top management because it's the only game in town."

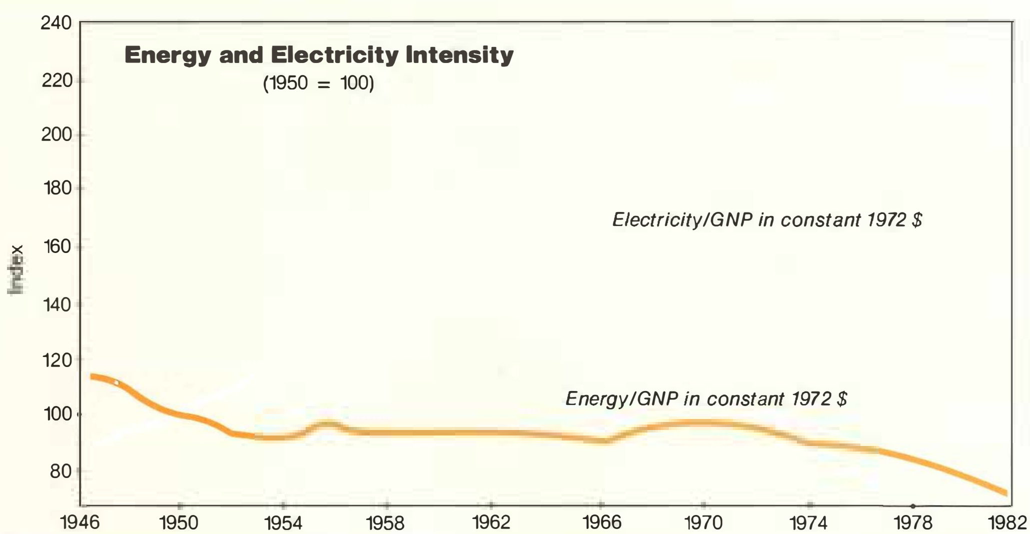
Sam Schurr

"Those that see a new trend toward lower electricity intensity are running a trend line only from 1975 on."

Impact of New Technology on the Intensity of Industrial Electricity Use

Application	Estimated 1983 Consumption (%)	Largest Users	Impacting Technologies by 2000	Probable Trend in Electricity Intensity
Electromechanical drives	70	• Chemicals • Pulp and paper • Foods • Primary metals • Petroleum refining • Textiles	• High-efficiency motors • Adjustable speed drives • Cogeneration	Down
Electrolysis	15	• Primary metals • Chemicals	• Improved cell efficiency • Chloride process • Membrane cells • Electrochemical synthesis • Membrane separation	Down
Electroheat	10	• Primary metals • Metal fabrication • Chemicals • Foods • Pulp and paper • Textiles	• Plasma reduction • Plasma melting • Induction heating • Laser heating • Electron beam heating • Electroslag casting • Plasma chemistry • Microwave and radio frequency heating • Infrared heating • Ultraviolet curing	Up
Other	5	All	• Robotics • Improvements in HVAC	Down

Source: Philip Schmidt



Source: Sam Schurr

truth," said James Cook, "is that we really don't care about the unemployed as long as we don't have to confront their numbers. But we can't cope with the problem by sweeping it under the rug. The numbers are now simply too formidable."

And Gus Tyler of the International Ladies Garment Workers Union extended the looming unemployment problem to its ultimate dilemma when he said, "If artificial intelligence is limited to manufacturing, I suppose we don't have to worry too much as long as other sectors of the economy can absorb those displaced. But if artificial intelligence can also be applied to banking, offices, teaching, government services, and so on, then I think we have an entirely new problem. In short, if artificial intelligence eliminates jobs not just in manufacturing but in every other sector also, then I don't think we can say all we have to do is retrain and reeducate. That will be frustrating and meaningless unless the jobs are there."

Many felt that the nation is ill-prepared to deal with massive structural unemployment and that some type of public policy may be required before a political backlash of threatened workers and businesses undermines or retards the very steps necessary to ensure competitive strength and jobs. "Right now there is an ineffective maze of 22 federal grant-in-aid programs for displaced workers," according to Pat Choate, "and public policy on employment is concerned almost exclusively with those not in the work force, primarily youth and the disadvantaged. Reform is required. At its core, public policy must ensure that employers are given incentives for increased investment in worker skills just as they are given incentives for increased investment in modernized plants and equipment."

Retraining and relocation will be neither easy nor cheap, and the flexibility of the worker is limited. It was mentioned that 90% of the 1990 work force is now adult and that one out of five is said to be dysfunctional (i.e., unable to read, write, or count). This would seem to limit what realistically can be done in shifting people about to meet the changing needs of a technologic society. Several participants stressed that retraining has never really worked very well and that even though new jobs are created, the people who are losing the old jobs are not the same people who are getting the new ones.

The point was made that the substantial costs to the nation of the displaced worker can only be shifted about, not avoided, and the costs of inaction could well exceed any national program. As Raphael Thelwell, director of economics for the NAACP, said, "If the United States decides and accepts the premise that full employment means 7–8% unemployment, then that cost in human life must be borne by this society no matter how we slice it. Eight percent is a considerable cost that will, of course, reduce our competitiveness."

Implications for energy

Two central questions settled in on the participants as they explored U.S. energy use in the context of sweeping industrial change: where is energy consumption headed and can electricity or electric-based technologies play a role in revitalizing American industry?

Sam Schurr offered some valuable historical perspective. For eight decades low-cost energy was a major spur to American industrial expansion, in large measure by lifting the productivity of other input factors, such as labor. Thus, even as energy consumption grew, industrial output grew still faster. The result was that energy intensity (energy input/GNP) trended downward over the years.

The notable exception has been electricity, the intensity of which (electricity input/GNP) has historically climbed. In the 1920s electricity intensity took a major leap upward as industry shifted from steam drive to electric drive and as electrification took firm root throughout American society. Similar jumps, noted Schurr, occurred just as the nation was moving out of the Depression and at the end of WWII, two periods when pent-up

Albert Sobey

"General Motors . . . has an active program to improve in-plant energy consumption, and we are showing a 3–4% per year improvement."

Ron Wishart

"The chemical industry is in a worldwide competitive situation. In a period when physical output was up 45%, our total energy appetite was down 4%, while purchased electricity was up 23%."

Philip Schmidt

"Direct process heating . . . can have a tremendous impact on productivity. This is the one area where I can rationalize a possible upward trend in electricity intensiveness."

demand surged toward electric products and processes. By 1950 industry was consuming 60% of the nation's electricity and the commercial and residential sectors, the remaining 40%.

In the three decades of the postwar years, electricity consumption patterns have shifted noticeably toward the commercial (i.e., services) and residential sectors. Electricity intensity in the residential area is now four times what it was in 1950, commercial three times, and industry two times. The result is that each of the three sectors now accounts for roughly one-third of total consumption.

The long historical climb in electricity intensity stalled in the mid 1970s for reasons not yet entirely clear. Price and the effects of conservation undoubtedly contributed, but so did the sluggishness of the overall economy. GNP, notes Schurr, grew only 2.8% for the entire four-year period 1978–1982. "In summary," Schurr said, "those that see a new trend toward lower electricity intensity are running a trend line only from 1975 on."

Judging from the comments of the speakers from basic industries, the cost crunch is leading to a decidedly downward trend in overall energy use in American industry. Electricity, however, is a more-mixed bag. As a commodity, it is subject to the same cost-cutting pressures; but as an energy form precisely controllable, it is indispensable to the automation technologies and electronic intelligence of tomorrow.

Henry Singer, whose position as vice president of industrial sales for General Electric gives him access to dozens of industries, said, "In the discrete parts industries—everything from autos to dishwashers to integrated circuits—the drive for automation should create some new, albeit not larger, opportunities for electric power. But in the process industries, such as chemicals, metals, pulp and paper, electricity is viewed as raw material and every effort is being made to drive use and cost down. The overwhelming perception is that electric costs will rise rapidly and erode profits."

From the standpoint of General Motors Corp., Albert Sobey, director of energy economics, said, "General Motors spent $1 billion last year for energy, 60% for electricity. We have an active program to improve in-plant energy consumption, and we are showing a 3–4% per year improvement. We are now down 35% from where we were in 1973. . . . As for the future of the electric car, we see it only as a special purpose vehicle. Our current arithmetic shows that for the electric car to be economic, gasoline would have to exceed $3 a gallon and electric power costs would have to stay where they are, an unlikely combination."

Ron Wishart, director of energy and transportation for Union Carbide Corp., said, "The chemical industry is in a worldwide competitive situation. In a period when physical output was up 45%, our total energy appetite was down 4%, while purchased electricity was up 23% primarily because we replaced steam drives with electric drives in order to improve productivity."

The long-term trends in electricity intensity in American industry can be partially discerned by the major new production technologies now on the horizon. Philip Schmidt, professor of mechanical engineering at the University of Texas, speculated on the overall impact these new technologies would likely make on each of the four broad areas of industrial electricity use: electromechanical drives (about 70% of U.S. industrial electricity consumption), electrolysis (15%), electroheat (10%), and other, primarily lighting and HVAC (5%). In all but electroheat, the "technology trends are tending to make electricity use less intensive per unit of output, meaning that we can expect electricity use to grow at less than the rate of growth of these industries."

In the largest consuming area, electromechanical drives in the process industries, he pointed out that the incorporation of higher-efficiency motors and adjustable speed drives, particularly solid-state ac controllers for larger motors, will tend to reduce per-unit electricity requirements. He also noted that these industries are excellent cogeneration candidates because of their balance of steam and electricity use.

In contrast, he views direct process heating as a major target of opportunity "because here electric processes can have a tremendous impact on productivity. This is the one area where I can rationalize a possible upward trend in electricity intensiveness. And I should put a big question mark here because it really becomes a question of the readiness and economic ability of these industries to adopt new methods of production."

Looking comprehensively, then, at future industrial demand, the electric utility industry is facing something approaching irony: encouraging change in manufacturing that may well reduce its consumption of electric power. More specifically, electricity and electric-based technologies in the broadest sense, ranging from high-efficiency motors to electronics to plasma arc reduction to computers to robotics, are absolutely essential to future manufacturing competitiveness and must be encouraged despite the possibility they could (at least in aggregate) reduce industrial electricity consumption. Failure to promote such productivity improvements could only weaken the manufacturing base that underpins and lifts the service and residential sectors, where some two-thirds of the electricity consumption now rests and where growth potential continues to be strongest.

Electricity continues to have a circular relation with the general economy and the real question becomes one of how fast or how slow to spin the wheel: electricity and electric-based technologies push productivity, which in turn pushes the economy, which in turn pulls electricity demand and generates capital for employing new electric-based technologies to enhance productivity.

A. J. Pfister, general manager of the Salt River Project and chairman of the board of EPRI, seemed to speak for the optimistic side of the electric power industry when he said, "I for one question the accuracy of the current low forecasts. The next 10 years will be as different from expectations as the last 10, and the probability is greater that we are now projecting too low. As prices of electricity moderate, consumption will pick up; 2–3% may be too low."

Citing a recent study by Mathtek, Inc., Justin Moore, chairman of the board of Virginia Electric and Power Co., held out the prospect of an average 2–4% per year growth through the turn of the century but with wide swings in between. "For the 1990s," he said, "the study shows industrial electricity use growing twice as fast as in the 1980s—somewhere between 1.5 and 1.7 times the growth of GNP."

Meeting a resurgence in demand could be a problem in some regions of the country where reserve margins are low. Thomas Page, president of San Diego Electric and Gas Co., commenting on what he saw as an overlooked supply option, said, "I think that in ten years, when we look back, we are going to be in considerable awe at our shortcomings in moving power around."

EPRI's role

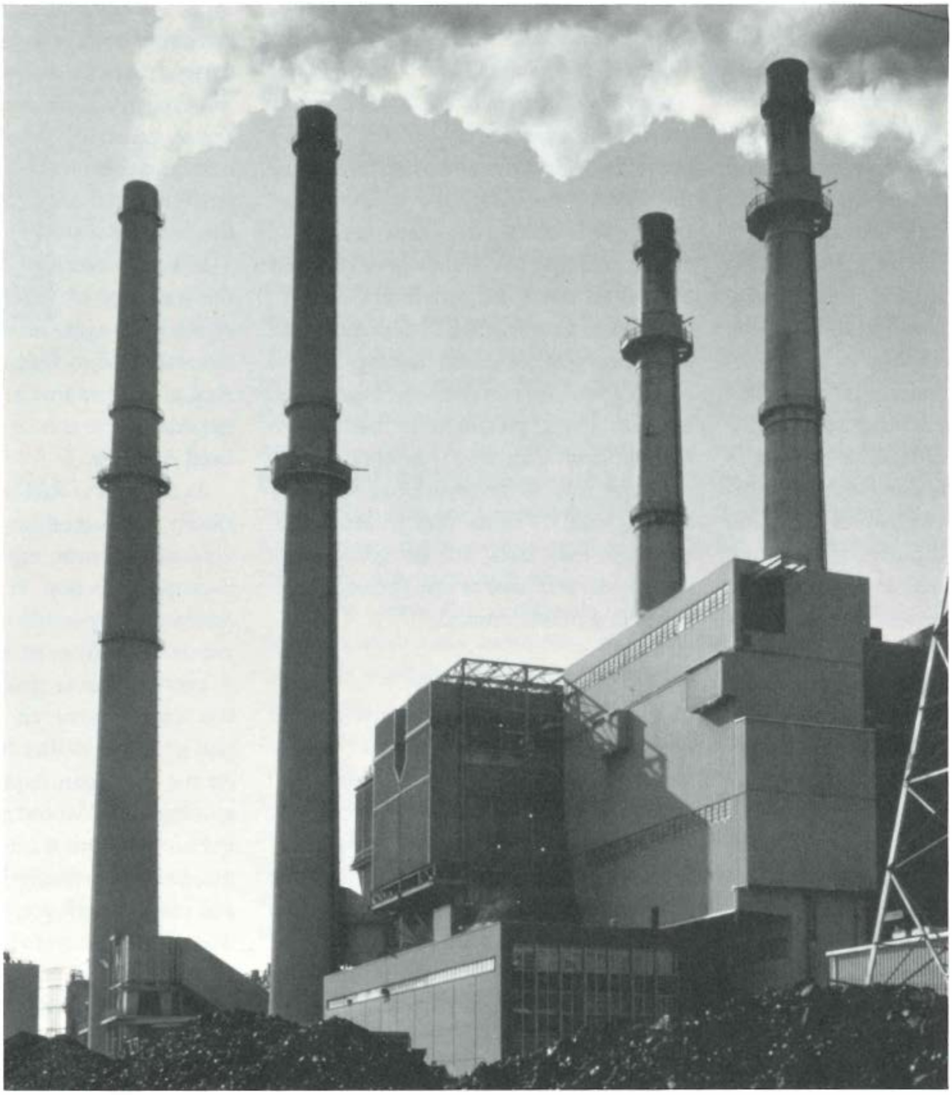
Upgrading the competitive strength of American manufacturing was widely viewed as necessary for revitalizing U.S. economic growth; and in that context, EPRI's president, Floyd Culler, asked the Institute's assembled advisers and guests to what extent EPRI should catalyze the development of specific electrotechnologies that could enhance the productivity of American industry. . . . These would be limited joint undertakings with basic industry to seed and establish R&D centers.

Responding, Philip Schmidt for one said he was "baffled by EPRI's uncertainty about getting involved; I know of no other industry that vacillates on doing research on the applications of its products." He pointed to the R&D efforts by EPRI's counterparts in France, United Kingdom, West Germany, and Australia, adding that the United States currently lacks a focal point for such research. But Stanley York, commissioner on the Wisconsin Public Service Commission, brought a sense of caution to the deliberations when he attempted to capture public concerns about efforts that could lead to, or be construed as leading to, electricity marketing. "As a regulator," he said, "I'm ambivalent about the appropriateness of utilities trying to sell more electricity, particularly in situations where the capacity is limited and where additional capacity will raise average unit costs and conceivably create social costs—environmental costs—that might outweigh the benefits of selling more electricity."

In a microcosm these views exemplify the inability of particular parts of the economy to agree on what is in their best interests and to find a course of action. And in the end this may be the only real impediment to the can-do spirit of mobilized America.

As a leader in R&D management, EPRI clearly has something to offer to the revival of American economic growth. But it cannot function in isolation, and the reality of partnership must become a prerequisite to any expansion of EPRI's role. A prescription to guide EPRI's prospective involvement in applications R&D was given by Walter Marshall, reflecting on his European experience. "If I were guiding you, I would say first to remember how difficult it is to get the American utilities who actually fund you to accept and use the work you have done and take that as a lesson as to how difficult it is to accomplish technology transfer from a research organization into a business organization. And then remember that the step from EPRI to the utilities is actually easy compared with anything else you would set yourself to do. Therefore, you measure your success [in applications R&D] by whether that technology transfer step can take place. If you succeed, then the work is justified, and if you fail, do not be ashamed to cancel out the program rapidly. . . . Provided that is your guideline, you will find it such a severe limitation that you will not need any other limitations whatsoever." ■

FINDING THE WEAK LINKS IN POWER PLANT AVAILABILITY



Doubling the reliability of a given component may or may not have a significant effect on overall unit availability. An inexpensive, easy-to-run computer model can isolate critical components and predict the impact of component changes and modifications.

Utilities have faced intensifying pressures in recent years to make their most efficient units available for operation a high percentage of the time. On one side loom the cost pressures brought on by dramatic increases in fuel prices; on the other, deteriorating plant performance and reliability. Also, some states now require electric utilities to demonstrate that their planned units can achieve specified availability levels.

Outages raise the cost of electricity, and it is becoming much too expensive to iron out bugs in plant design after a plant is in operation. Since late 1978 EPRI has sponsored the development of a promising methodology that assists utilities in evaluating the impact of potential plant modifications on availability before committing resources to plant construction. The methodology, based on a software package known as UNIRAM, models a generating unit's reliability, availability, and maintainability (RAM) characteristics and enables utility analysts to assess the impact of design changes, spare parts inventory, and corrective maintenance practices quickly and at low cost.

The primary inputs to the model are component reliability and maintainability data derived from operating experience, expert estimates, and unit operating capabilities. The outputs are RAM measures that enable analysts to get a clear picture of the effect of a given component failure on overall unit availability. The payoff of the methodology is greater understanding of the complex factors that keep a plant up and running—and, of course, the cost savings born of the improved plant performance that results.

EPRI first developed the RAM methodology for advanced power systems. Its first application in 1980 was an analysis of the reliability and availability of integrated coal gasification–combined-cycle (IGCC) units. Since then, EPRI projects have used RAM analysis to evaluate the availability of other advanced technologies, such as geothermal and synthetic fuel plants and conventional coal-, oil-, and gas-fired units.

A flexible new tool

The EPRI methodology has gone through several steps in its evolution. Arinc Research Corp. of Annapolis, Maryland, developed the first model for IGCC units with assistance from Fluor Engineers, Inc.; EPRI reviewed component data, plant design, and operating procedures. The methodology began as an attempt to analyze plant reliability—that is, the frequency with which failures occur—but soon expanded to consider a measure of availability that included corrective maintenance efforts.

The original IGCC analysis evaluated three configurations of a conceptual 1150-MW baseload unit designed by Fluor: one baseline configuration that included a spare gasifier, one design with no spare, and one that added a spare gas turbine–heat recovery steam generator system. The analysis considered both full and partial outages, assumed normal preventive maintenance, and used a combination of publicly available data and expert estimates. The results, reported in January 1982, provided useful insights into the relative availability of the three configurations, as well as the ranked importance of each major component for unit availability—both of which will assist in future IGCC designs.

EPRI then decided to test the overall validity of the RAM methodology and accompanying software developed for the IGCC application on three alternative coal-fired units. One design was that of an actual 350-MW (e) baseload pulverized-coal-fired plant designed and constructed by Fluor and in operation since 1974. The other two designs were hypothetical. Test Case 1 (TC1), also designed by Fluor, was a 550-MW (e) state-of-the-art unit with flue gas desulfurization (FGD) planned for startup in the mid 1980s. EPRI adapted TC1 to create the third design, Test Case Modification 1 (TCM1), which removed redundant FGD, limestone mills, and other subsystems in order to more closely represent typical, currently operating coal-fired units.

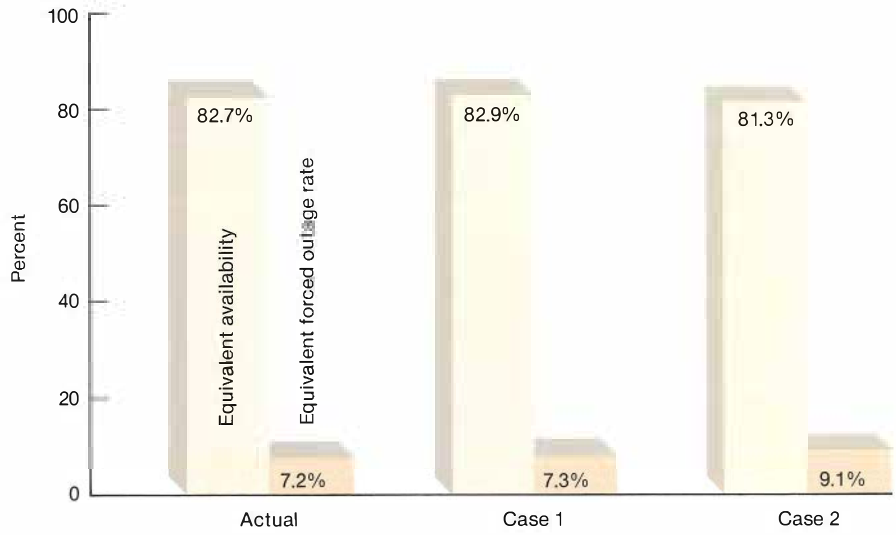
In evaluating the first unit, project personnel compared model predictions with historical availability data. They found that predicted values matched historical values (drawn from outage reports) with only 0.1–0.2% absolute difference. For TC1, they sought to determine whether UNIRAM predictions were consistent with expectations for the state-of-the-art design; for TCM1, they looked for a match between predicted performance and utilities' actual experience with this class of unit.

Again, the analytic approach yielded positive results. The RAM methodology and assumptions were shown to be valid, UNIRAM functioned properly, the accuracy of the estimated data proved sufficient for useful analysis of the hypothetical designs, and analysts could easily evaluate and compare the design options. Project leaders determined that the industry could confidently use the methodology to evaluate alternative technologies and to verify the availability improvements possible through building in selective redundancy or other improvements.

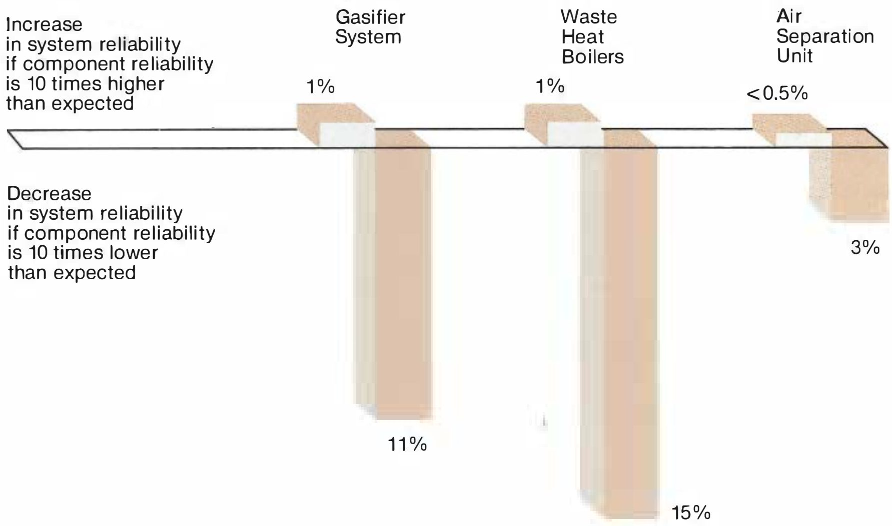
A number of utilities are currently using or adapting the UNIRAM model, including Union Electric Co., New York State Electric & Gas Corp., and Public Service Co. of New Mexico. In addition, Houston Lighting and Power Co.; Carolina Power & Light Co.; Consolidated Edison Co. of New York, Inc.; Philadelphia Electric Co.; Pennsylvania Power & Light Co.; Baltimore Gas and Electric Co.; and Southern Company Services, Inc., among others, are considering use of the RAM methodology in the near future. Users have applied RAM analysis to a wide range of concerns, including life extension planning, availability improvement, maintenance planning, FGD design, and subsystem and unit evaluations.

The flexibility of the methodology is one of its greatest attractions, according to Jerome Weiss, project manager in the Engineering and Economic Evaluations Program of EPRI's Advanced Power Systems Division. "It is easy to learn, easy to use, and inexpensive," he states. Experience shows that an engineer knowledge-

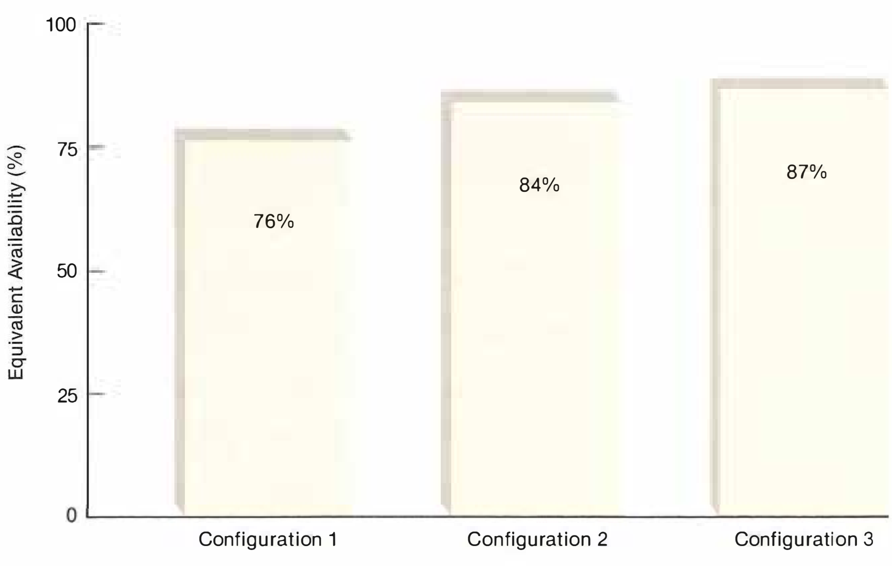
Actual availability and forced-outage rates for a specific coal-fired plant are compared with predictions generated by the RAM model. In Case 1, historical data on the plant's component failures and capacity levels were used as model input to test the validity of the model itself. In Case 2, input data to the model were estimated for a generic coal plant of the same size from industry data and expert opinion. The closeness of these results to the actual plant figures demonstrates the model's insensitivity to poor data quality and its potential for successful widespread use.



Sensitivity of gasification-combined-cycle plant reliability to changes in the failure rate of selected components. RAM analysis shows that the overall system is much more sensitive to large-scale decreases in component reliability than to large-scale increases. Some subsystems, such as the air separation unit, are unlikely to significantly affect availability even when their failure rates are drastically altered.



RAM assessments of a conceptual 1150-MW gasification-combined-cycle system showed that equivalent availability could be increased significantly by adding key spare subsystems to the basic design. Configuration 1, with no spares, scored a good deal below Configuration 2, which adds an extra gasification train. Although Configuration 3, with both a spare gasification train and a spare gas turbine-heat recovery steam generator system, offers still better figures, its availability improvement over Configuration 2 must be weighed against its considerably higher capital cost.



able about a unit's design can familiarize himself with the methodology and prepare a RAM analysis in two workweeks (exclusive of data collection, which varies widely depending on the quality and availability of the data needed). Moreover, according to Weiss, "one can gain useful insights by using the methodology even without especially good data."

EPRI has found good use for the methodology in recent major projects. In developing the Cool Water IGCC demonstration plant, for example, a RAM analysis of four possible configurations led designers to incorporate a spare gasifier to provide a more satisfactory expected level of availability for the plant. And in designing the Heber geothermal binary-cycle demonstration project during 1980–1981, a UNIRAM analysis helped confirm the reliability of the overall plant configuration. When these two demonstration projects have been completed, analysts will be able to compare the data they generate with UNIRAM predictions for further confirmation of the model.

The RAM analysis

The RAM methodology is a logical and straightforward step-by-step process. The first step is to partition the unit into subsystems to make the analysis manageable. Basic subsystems are groups of components whose failures have identical effects on power curtailment. In a coal-fired unit, for example, all full-capacity systems (such as ash-handling and steam systems) might make up one basic subsystem, with systems of less than full capacity making up several others. These basic subsystems then become part of progressively larger, nested subsystems that together represent the entire unit.

The next step is to create a fault tree for each basic subsystem to graphically delineate ways in which each subsystem can fail as a result of failures of its components. The fault trees use logical operators such as AND and OR gates to show how component failures or combinations of failures cause the subsystem to fail.

After these first steps define the model structure, a utility acquires or estimates component reliability and maintainability data that realistically reflect actual or potential operating experience. Developers of the methodology have found two descriptors particularly useful in the analysis: mean time between failures (MTBF), which is the average number of operating hours logged by a component between its forced outages; and mean downtime (MDT), the average time to restore a failed component.

For existing plants, work orders and outage/generation reports are the best sources of this information. For many advanced power systems, however, such information may not yet be available; in these cases, analysts must rely on expert estimates, data on comparable components, or both. A number of public data sources can assist in this effort, and EPRI also has generated two data books in the course of its UNIRAM work.

Producing MTBF estimates is generally more straightforward than generating MDT estimates because the latter vary according to the failure mode; its relative frequency; times for repair, shutdown, and startup; and administrative or logistic delays (e.g., spare parts inventory levels). Most data collection methods are less than perfect, but UNIRAM's developers find that sensitivity analyses can offer insights into the relative effects of uncertain data. In addition, UNIRAM can accept ranges of estimates as well as single estimates for component data. The output in this case includes averages and standard deviations of plant RAM measures.

The model is "user friendly." An interactive preprocessor program helps the nonexpert prepare input files through structured queries, error handling, automatic processing of design changes, and automatic formatting. Written in FORTRAN IV, UNIRAM is compatible with a wide variety of computer systems; users also have the option of accessing UNIRAM through a commercial time-sharing service.

UNIRAM's developers have made it highly adaptable to different generating units. In most cases, only the input data need change from application to application; changes in the program are usually unnecessary.

UNIRAM results

The results of a baseline run of UNIRAM are predictions of various performance measures (including availability, equivalent availability, forced outage rate, and equivalent forced outage rate) and a list of state definitions, corresponding output capabilities, and their probabilities of occurrence. UNIRAM defines unit operating states and their output capabilities on the basis of subsystem structure and throughput capacity information in the input data file.

Current additions to the program will allow the user to model special kinds of degraded operating states. The last step in the RAM methodology—sensitivity analysis—is the one that makes performance insights possible. By varying failure rates, restore rates, and subsystem availabilities, utilities can determine the effect of each change on the plant's steady-state availability. Varying the design configurations allows identification of those improvements that will have the greatest impact on availability, as well as the magnitude of their impacts. Rankings of components' criticality can be a first step toward practical planning and design efforts.

In EPRI's first RAM analysis in 1980, sensitivity analyses showed that the gasifier was clearly the most critical component in each of three generic IGCC configurations. Further analysis showed that the coal-handling subsystem had the greatest impact on availability. As a result, the Cool Water plant has a 100% redundant coal-grinding system and an 80% redundant gasifier system.

Sensitivity analyses of the coal-fired units in EPRI's later validation study showed that TC1's standby FGD system accounted for more than half its performance advantage over TCM1 and that the

Estimated Effect of Subsystem Outage on a Typical Coal Plant

Subsystem Group	Number of Systems Unavailable	Plant Output Level (%)
Coal silo, mill, feeder, pulverizer, exhauster, burner	1	76.7
	2	51.2
	3	28.5
	4	0.0
Boiler circulation pump	1	69.1
	2	0.0
	3	0.0
Boiler feed pump	1	89.1
	2	0.0
Condensate pump	1	100.0
	2	80.3
	3	0.0
Induced-draft fan	1	88.8
	2	0.0
Feedwater heater	1	92.4
	2	83.6
	3	0.0
Circulating water pump	1	80.0
	2	0.0
Forced-draft fan, air heater	1	95.8
	2	0.0
All full-capacity equipment	1	0.0

standby sulfur dioxide absorber in TC1 gave it an advantage of 4.5 percentage points in equivalent availability over TCM1. Sensitivity analyses of the one operating coal-fired unit in the study indicated that MTBF estimates were more accurate than MDT estimates and one-third of the components accounted for almost all forced outages and deratings.

Though the results of such analyses may simply confirm utilities' intuitive knowledge, Weiss reports that they can also contain surprises. "The frequent failure of one component may not be as important as the infrequent but more significant failure of another," he points out. "One can assume that one component is the culprit only to find out that its role in a complex system failure is relatively insignificant. A key contribution of our model is that it helps you decide which component failures contribute most to system failure."

The future

Using the information provided by a RAM analysis, utilities can take the next step of relating UNIRAM insights to operating, capital, and replacement costs. More reliable equipment frequently requires a greater capital outlay, while less reliable equipment generates higher labor and parts costs. A spares provisioning plan can help balance unavailability costs against excessive capital costs.

One possible extension of a unit-level RAM analysis is to investigate RAM trends between units, subsystems, and components. Another is to measure RAM improvements stemming from service changes, equipment changeovers, component improvements, or revised maintenance practices. Both these capabilities exist now and are likely to attract ever wider application.

The methodology can provide valuable input for utility planning efforts. It has potential for forecasting plant availability levels, for example, or for meshing with utilities' outage reporting systems to forecast unit productivity trends. In any case, use of the RAM methodology becomes increasingly attractive, given rising replacement power costs, increased complexity of the power plant design, and the current trend toward availability improvement programs. As industry analysts look toward future requirements for more cost-effective power plants with greater emphasis on plant availability, they are increasingly likely to need the capability of UNIRAM as an aid in their decision making. ■

This article was written by Adrienne Harris Cordova, science writer. Technical background information was provided by Jerome Weiss, Advanced Power Systems Division.

Further reading

Users Guide for the UNIRAM Availability Assessment Methodology. Final Report for RP1461-1, prepared by Science Applications, Inc., December 1983. EPRI AP-3305.

Reliability and Availability Analyses of Coal-Fired Units: Validation of a Predictive Methodology. Final Report for RP1461-1, prepared by Arinc Research Corp., March 1983. EPRI AP-2938.

Guide for the Assessment of the Availability of Gasification–Combined-Cycle Power Plants. Final Report for RP1461-1, prepared by Arinc Research Corp., January 1982. EPRI AP-2202.

Component Failure and Repair Data for Coal-Fired Power Units. Topical Report for RP239-2, prepared by Fluor Power Services, Inc., October 1981. EPRI AP-2071

Federal Energy Sources On-Line

Computers have brought a new measure of control to the challenge of energy information management in the federal sector.

Information proliferation has become a particular problem in the energy arena since R&D became a sudden national priority. The rapid growth of information resulted in a need for structured techniques to identify, locate, and retrieve relevant material. Policymakers and planners require timely information to proceed effectively in their work. Researchers must be aware of the results of previous investigations to progress without wasteful duplication. Even as the research advances, new energy issues emerge and information must be assembled in new patterns to address the problems and identify and communicate potential solutions. Perhaps most important, the research results must be transferred to the energy industry for analysis, demonstration, and implementation.

Computerized bibliographic data bases can provide support for all these information needs. Large data files, made possible by high-speed processing and expanding storage capabilities, centralize information collection and storage. Remote access to the data bases, made possible through advances in telecommunications, allows anyone with a terminal, a telephone hookup, and a few hours of training to search these large central files. A typical search on a bibliographic data base can be completed within 15 minutes at an average cost of $15–$20, including telecommunications charges, computer time, and printed summaries of the records received. The cost is somewhat less if the summaries are printed off-line and mailed to the searcher.

There are many data bases devoted to a broad spectrum of energy concerns. Although most commercial files are produced in the private sector, the federal government, which has been called the world's most prolific publisher, has also developed computerized resources to aid in the management and identification of specific categories of energy information. In fact, the world's largest on-line bibliographic file containing information on energy is DOE's Energy Data Base (EDB).

DOE's Data File

Compiled and maintained by DOE's Technical Information Center, Oak Ridge, Tennessee, EDB comprises more than 2 million citations to energy literature. It is essentially an electronic catalog of references to information contained in widely dispersed and variously formatted sources. For each item referenced, a thorough bibliographic description is provided, and in most cases, abstracts and extensive indexing help to establish subject content more precisely. The author, type of document, date, keywords, and other identifying information are the multiple access points that enable a searcher to retrieve the references of interest.

Nearly half the items referenced on EDB are journal articles. Other materials cited include technical reports, books and monographs, patents, dissertations, conference proceedings, papers, and translations, as well as engineering drawings and even an occasional letter to the editor, editorial, book review, or interview. Given access to a central data base, scientists do not have to devote their own time to monitoring this wide variety of sources for relevant material.

According to Elizabeth Buffum, associate manager of DOE's Technical Information Center, "The Energy Data Base provides a central information resource for use by all DOE scientists and engineers, which helps to avoid duplication and overlap, representing significant savings in time and materials. In fact, a recent analysis of EDB's value to the scientific community concluded that its availability can increase a scientist's productivity by over 50%. When you consider the cross-cutting nature of much of energy information, it is clear that a specialist couldn't possibly keep up in all those fields without some kind of centralized source."

The multidisciplinary mix of materials contained in the energy literature is evident from the range of subjects covered in the EDB file. Its 20 broad categories include citations on renewable resources, fossil, nuclear, and other sources of energy; scientific disciplines, including the physical, environmental, and applied sciences; and an assortment of current and advanced technologies. Also covered are specific topics relating to national energy objectives, such as energy conservation, consumption, and end use.

Although the primary users of EDB are some 60,000 government researchers located at over 6000 sites, the file contains material of value to a broad cross section of the energy community. For example, a portion of the file is devoted to information of interest to energy planners and policymakers. Coverage in this area includes energy policy and management, impacts of new energy technologies, and social, political, and environmental issues.

EDB's comprehensive coverage is not restricted to the 10 years EDB has been in existence. Material on magnetohydrodynamics, for instance, reaches back to 1957; other items date back as far as the late 1800s. There are also unique materials from specific historical eras that further enrich the quality of the data base. For example, previously unpublished basic research on coal gasification and liquefaction produced by the German synthetic fuels industry during World War II appears in the fossil energy portion of EDB.

In fact, to ensure that EDB is as comprehensive as possible, coverage of the literature extends to the leading scientific literature published throughout the world. As Buffum explains, "This is due in part to a shift in the origins of research information. Although the United States once conducted two-thirds of the world's basic energy science work, that figure has now dropped to only one-third. To accommodate this shift, the Technical Information Center has negotiated arrangements with a number of countries and international organizations for the exchange of energy-related information."

The first such arrangement was made in 1970 with the International Nuclear Information Systems, established within the International Atomic Energy Agency (IAEA). By 1982 at least 69 countries and 13 international organizations were participating in the exchange program. During 1981, the United States contributed 21,000 information items and received some 50,000 in return. Similar agreements involving other subject concentrations, such as coal and biomass, have also been established through umbrella arrangements centered in the International Energy Agency (IEA).

Although international information is stored on EDB, access to the file by other countries is limited. "We don't make the data base available outside this country in any form unless it is through some form of quid pro quo agreement," explains Buffum. "The Technical Information Center does not sell data bases, nor does it try to compete with the private sector. We have developed a service for DOE contractors and employees and made it available to them on RECON, DOE's internal on-line information retrieval system. But so that the academic, business, and other communities can take full advantage of the data base, we make the tapes available for lease to private vendors through the National Technical Information Service [NTIS]." These private vendors, however, are also able to limit international use of the EDB file by restricting password access.

In short, EDB is itself a national resource. It is an electronic library that can be browsed by any U.S. citizen from any location in the country through such vendors as Lockheed-DIALOG and SDC. Although EDB simplifies access to scientific and technical information, gaining access to copies of the material cited is a different matter. Because half the items on the data base appear in journals, these citations are available in the open literature. But much of the remaining material is not widely available. As Buffum points out, "Scientific and technical materials are not the type of profitable literature to be picked up for sale through private organizations. Because of this, NTIS was established to serve as a public outlet for government report information and to become a permanent archive to ensure continuous availability of those materials."

NTIS: An Information Outlet

The National Technical Information Service, an agency of the Department of Commerce, was established in 1964 to centralize the public sale of information—primarily reports—resulting from the

FEDERAL ENERGY INFORMATION SOURCES

DOE Energy Data Base

Lockheed Palo Alto Research Laboratory
3215 Hanover Street
Palo Alto, California 94304
(Accessed through Lockheed-DIALOG system, 800-227-1960)

Systems Development Corp.
2500 Colorado Avenue
Santa Monica, California 90406
(Accessed through the SDC–ORBIT system, 800-421-7229)

NTIS Data Base

Lockheed Palo Alto Research Laboratory

System Development Corp. (SDC)

Bibliographic Retrieval Services, Inc.
1200 Route No. 7
Latham, New York 12110
(800-833-4707)

GPO Publications Reference File

Lockheed Palo Alto Research Laboratory

GPO Monthly Catalog

Lockheed Palo Alto Research Laboratory

Bibliographic Retrieval Services, Inc.

Chemical Substance Information Network (CSIN)

Network Administration
Chemical Substance Information Network
722 Jackson Place, NW
Washington, D.C. 20006

multibillion dollar government research programs. With over a million titles on file, plus about 70,000 new items contributed each year from over 240 units of government, NTIS has an enormous wealth of information to manage. It is not surprising, therefore, that NTIS provides timely, thorough public access to its extensive collection through a computerized bibliographic data base. But the NTIS data base serves as more than a resource for references to material. The items identified from a search can be purchased directly from NTIS, and as an added service, they can now be ordered on-line.

The type of material referenced on the NTIS data base is generally very technical and therefore appeals more to the scientific, business, and industrial community than to the general public. Included are references to technical reports, over 1000 federally generated machine-readable data files and software, U.S. government inventions available for licensing, and translations of foreign government reports. Recognizing the growing importance of other countries' technical information to the conduct of U.S. business and government, NTIS has taken measures to increase the flow of such information to the United States. Over the last several years, it has established cooperating agreements with 88 agencies in 40 countries. As a result, approximately 20% of the material on the data base originates abroad.

The subject content of the NTIS data base is as varied as the multitude of organizations contributing materials. Energy is only one of many subjects covered because federal R&D activities extend to other areas, such as the behavioral, social, and health sciences. However, as DOE is one of the three largest contributors to the data base, an estimated 25% of the items are energy-related. Subjects of interest to the energy community include technology applications, regulatory matters, electrotechnology, environmental pollution and control, nuclear science and technology, and technology transfer.

As the NTIS archive continues to grow, the data base will increase in importance. Its worldwide availability provides a critical bridge between the international investment in R&D and the return that comes from that investment when results are moved along for practical application by business and industry.

GPO: Index of Publications

Another major federal data base linked to the public sale of government documents is the Government Printing Office's Publications Reference File (GPOPRF). This data base covers materials that have been published or are soon to be published by the GPO. With over 25,000 references, GPOPRF indexes a variety of document types generated by the legislative, judicial, and executive branches of the U.S. federal government.

Among the executive branch publications are presidential statements, agency annual reports and surveys, maps, regulations, treaties, periodicals, pamphlets, and how-to brochures. Coverage of congressional documents includes hearings, bills, laws, and committee and subcommittee documents. In fact, GPOPRF is the only on-line source covering Senate and House hearings of private and public bills and laws.

The GPOPRF data base, like the NTIS file, contains a broad range of topics because the material originates from many federal sources. But in addition to covering the many energy-related documents produced by Congress, GPOPRF includes surveys, assessments, handbooks, reference guides, and assorted brochures on energy produced by DOE and other cabinet-level agencies. Availability of these documents is generally assured for a period of 18 months, but unlike NTIS, GPO is not set up to serve as an archive of all documents announced for sale. Items that are currently in stock are noted as such, but many are not reprinted once the initial supply has been exhausted. GPOPRF is therefore most valuable for the timely identification, verification, and selection of new federal publications as they become available for sale through GPO bookstores and warehouses.

All the items on GPOPRF are also indexed by another GPO-produced data base. This second on-line file corresponds to the hardcopy version of the *GPO Monthly Catalog*. Because the catalog indexes publications of the federal government, not just those published by GPO, it is a much larger file. Containing over 160,000 references, the on-line *GPO Monthly Catalog* is a useful reference tool for tracing all the items appearing on GPOPRF, as well as many more analyses, conference proceedings, industry reports, standards and safety studies, projections, statistics, and state-of-the art summaries published by the federal government since 1976.

Although neither of the GPO data bases provides fully comprehensive subject coverage of energy documents, the on-line access they provide to many types of federal documents offers a convenient source for locating a steadily growing volume of information not represented on the more technically oriented federal files.

CSIN: Multiple Searching

The Chemical Substance Information Network (CSIN) is a project of the Interagency Toxic Substances Data Committee (ITSDC), an oversight body cochaired by the Environmental Protection Agency and the Council on Environmental Quality. ITSDC is responsible for reviewing and coordinating the information activities of a number of federal agencies involved in the production, collection, and processing of chemical data and information.

Retrieval of chemical data is complicated by the fact that there are now over 200 data bases that contain information relevant to the life cycle of chemical substances. Not only are these data bases geographically dispersed and maintained in different kinds of computers, but the information is stored in various formats, accessed according to different search languages, and indexed according to different methods. Thus a researcher requiring information on a specific chemical's properties, structure, effects, uses, origin, manufacturer, toxicity, and associated regulations would normally have to invest a great deal of time, effort, and money to search all the data bases carrying specific portions of that information. CSIN was created to minimize the burden associated with such information-gathering routines.

CSIN is not a data base, but a computerized management system linking together geographically separated data bases from such systems as Lockheed's DIALOG, SDC's ORBIT, National Library of Medicine's MEDLARS, NIH/EPA's Chemical Information System, and several others. It can be thought of as an intermediary information management device connecting the user to a combination of possible data bases from public and private vendors without requiring the user to know the various search languages, indexing terms, and system protocols specific to each data base. And vendors do not have to rectify the variations among their data base systems because the CSIN software itself is designed to overcome such inconsistencies. The user selects which files will be searched, but the telephone connections to the various data bases, the procedures for logging on and off, and even the search strategies are performed by the CSIN system itself.

Systems like CSIN may well become the wave of the future as more data bases enter the market and increase the level of information proliferation. Benefits will be similar to those derived from individual data bases, such as the EDB, NTIS, and GPO files. But they will be achieved on an even broader scale. The faster response times made possible by coordinating searches in and among several data bases will promote higher levels of productivity and ever more convenient aggregation of data pulled from dispersed electronic sources. In addition, information files produced by government, private industry, and the universities will be pooled, allowing for increased sharing of our national information resources. ■

This article was written by Mary Panke, Washington Office.

R&D Center for Metals Fabrication in Operation

An EPRI-funded center will examine energy efficiency and productivity in metals fabrication and pursue new concepts for the application of electrotechnology.

An R&D applications center for metals fabrication, designed to help develop and implement electrotechnologies, began operations in September at Battelle, Columbus Laboratories in Ohio.

As potential users of electrotechnologies, in recent years manufacturers have been confronted by a bewildering variety of choices in new equipment and processes, without having a reliable and unbiased assessment of the pros and cons of different applications. A major part of the center's work will be to provide such information, with emphasis on productivity, to a network of electric utilities and manufacturing trade associations.

Although the center is currently being funded by EPRI, industry and government funding now being sought should reduce EPRI's share of the center's budget to 10% by the end of the current three-year, $1.6 million contract. Half of EPRI's research funding for the center is allocated to the metal heating program, and the remainder is divided between fabrication and metal removal and finishing processes.

Metal fabrication represents a significant segment of U.S. industry, serving as a manufacturer of consumer, commercial, and industrial products and as a supplier of components to other industries (such as transportation, chemicals, textiles, food, and energy). However, most medium- and small-size manufacturing companies are experiencing low productivity and are short on capital, making them vulnerable to more-efficient U.S. and foreign competitors.

R&D activities will focus on energy-efficient processes that enhance productivity in metal fabrication and related manufacturing industries. Objectives include resolving existing technical problems, reducing the costs and uncertainties surrounding the new technologies, and developing new uses for new technologies. Researchers will study both advanced electrotechnologies (e.g., lasers, robotics, high-speed plating processes, and computer-aided manufacturing) and improvements in traditional technologies (e.g., welding and induction heating).

Plans for the center materialized over the past 18 months through a series of meetings involving representatives of EPRI, the American Society for Metals, electric utilities, and manufacturers. Prospective programs for the center will be reviewed by an advisory council composed of industry, trade association, utility, and government representatives, as well as the EPRI program manager and industrial program committee.

With its research program and information dissemination activities, the center has the potential to play a key role in improving manufacturing productivity. Further information can be obtained from I. L. Harry, project manager, Energy Management and Utilization Division. ■

Coal-Water Mixture Is Possible Petroleum Substitute

A major test in Memphis, Tennessee, to determine if a coal-water slurry (CWS) can be used to replace oil as a fuel for electric utility plants has been successful. Completed in September, the 35-day EPRI-sponsored test was the largest and longest CWS trial to date in the United States, burning 2400 tons of slurry in a large boiler.

Because coal is an abundant domestic fuel, the extensive use of CWS could reverse U.S. dependence on oil, as well as save money. "Even at current world oil prices, CWS will be cheaper to use than oil," comments EPRI Project Manager Rolf Manfred.

CWS consists of approximately 70% clean, crushed coal mixed with about 29% water and about 1% special additives. The additives permit the slurry to remain stable during transportation, yet it can be handled like oil through plant pipes and storage tanks. (Slurries have the appearance and texture of a thin, black latex paint.)

Manfred says CWS offers a number of advantages over fuel oil to the electric power industry. "The fuel may be very attractive to utilities as a replacement fuel in boilers that burn oil or in coal boilers that have been converted to oil and whose reconversion is impractical." Also some sulfur and ash can be washed out of the coal during fuel preparation, and the slurry does not have to be dewatered before it is burned.

For the test, Atlantic Research Corp. of Alexandria, Virginia, supplied 2000 tons of the CWS mixture, with the remaining 400 tons coming from Slurrytech Inc., of Miami, Florida. Babcock & Wilcox Co., Bechtel Group, Inc., and EPA also participated in the project. Railroad tank cars carried the mixture to Dupont Chemical Co.'s Memphis plant, where it was fired in a boiler containing five B&W burners, each rated at 15 million Btu/h.

"This project was a dress rehearsal before we burn coal-water slurry in an electric utility boiler," explains Manfred. "The main objective of this project—to gain experience from handling and firing CWS continuously for at least 30 days—was fully achieved."

The month-long demonstration generated information about handling and quality control of the mixture, as well as generating information to be used in future tests. "If all goes well, coal-water slurry could be commercialized as a utility fuel within the next few years," says Manfred. ■

EPRI and CEGB Receive I–R 100 Award

In September EPRI was honored for a major development that will improve the economics and worker safety of nuclear power plants. An I–R 100 Award, presented annually by *Industrial Research and Development Magazine* to recognize the 100 products it considers the most significant technologic advances of the year, was given to EPRI for development of a chemical process called LOMI (low-oxidation-state metal ions), which removes radioactive deposits from the piping of nuclear plants.

EPRI's award is shared with the Central Electricity Generating Board (CEGB), the state-owned electric utility of Great Britain, which developed the LOMI process at CEGB's Berkeley Nuclear Laboratories. The project was funded by EPRI, with cost-sharing by CEGB.

The LOMI process provides an improved method for reducing radiation fields in nuclear power plants. During plant operation, the pipes that carry reactor cooling water become radioactive. Because these pipes are within the plant, they pose no hazard to the public; however, maintenance workers pass near the pipes when performing their duties.

The total radiation exposure to each worker is limited by law, which means that a utility must either decrease radiation from the pipes or increase the number of maintenance personnel to restrict the amount of exposure to each individual. The radiation is concentrated in a thin layer of corroded metal oxides on the pipe interiors. Chemical decontamination is a method used to dissolve this thin layer of radiation and wash it away.

Robert Shaw, senior program manager in the Nuclear Power Division, commented, "Utilities have been reluctant to use chemical decontamination to reduce radiation fields because of concern about corrosion and disposal of the dissolved radiation products." Most decontamination systems that have been applied use an acid to dissolve the oxides, which can damage the underlying metal and release oxides as particulates that can clog other parts of the circuit.

The LOMI process offers a solution to these problems, with the added advantage of rapid application, notes EPRI's Christopher Wood, inventor of the process and a former CEGB project manager. In a new application of solution electron transfer theories, LOMI dissolves all the corroded metal oxides quickly and prevents the formation of particulates, Wood notes. LOMI reagents form strong reducing solutions that remove the oxide layer without corroding the underlying metal. The dissolved oxides are removed from the plant through conventional ion-exchange techniques.

The system has been applied annually since 1980 on the Winfrith 100-MW (e) boiling water reactor in England with no significant corrosion, Wood said. "The decontaminations of the Winfrith plant are unusual in that the entire nuclear core, including the fuel, has been cleaned," he added. "Subsequent tests showed that the fuel was not damaged in any way." LOMI's first commercial application in the United States, carried out in 1982 on a steam generator removed from an operating nuclear plant, was also highly successful, according to Shaw.

The LOMI decontamination system has been patented by EPRI and CEGB. Negotiations on licensing the process are progressing with several organizations worldwide. ■

EPRI Cosponsors FGD Report

A periodic summary report containing the latest information on the status of flue gas desulfurization (FGD) in the electric utility industry is now being cosponsored by EPRI. The U.S. Environmental Protection Agency (EPA) and EPRI announced earlier this year that they will jointly sponsor the Utility FGD Survey Program, under which the summary report has been published since 1974. Formerly the *EPA Utility FGD Survey Report*, it has been renamed the *Utility FGD Survey*.

The report covers operational and planned domestic utility FGD systems and operational domestic particulate scrubbers. "This will offer electric utilities the opportunity to learn from the successes and failures at other FGD installations," explains EPRI Project Manager Charles Dene. "Utilities that are planning new units can obtain information about system suppliers, the use of various materials, alternative FGD system components, and many other important items of interest."

Dene said information on system design, fuel characteristics, and operating history is furnished by electric utilities, system and equipment suppliers, research organizations, and regulatory agencies. The report also includes discussions on problems and solutions associated with scrubbers and FGD systems. "Access to the program's data is still available to the public for a nominal fee, under EPA sponsorship," explains Norman Kaplan, EPA project officer.

The first edition of the new *Utility FGD Survey*, published at the end of September, contains all data collected since the beginning of the program in 1974. Of primary interest is the updated information for the period from July 1982 through March 1983. Supplemental reports will be issued on a quarterly basis.

The annual series will consist of one annual report followed by three quarterly report supplements. Pedco Environmental, Inc., of Cincinnati, Ohio, which has prepared the report for EPA since 1974, will continue to maintain a computerized data base, the flue gas desulfurization information system (FGDIS), from which the *Utility FGD Survey* is produced. ■

SURE Results Published

Weather and the influence of local sulfur dioxide emission sources are major factors in sulfate concentrations in the air over the northeastern United States, according to the final report of the EPRI Sulfate Regional Experiment (SURE).

The three-volume report provides a comprehensive perspective on air quality under fair weather conditions for the rural Northeast. SURE, an $8 million, seven-year study, was undertaken to define the relationship between local emissions of sulfur dioxide and regional ambient concentrations of particulate sulfate.

The research contained four elements: a ground monitoring network of 54 randomly distributed stations, instrumented aircraft for measuring air quality aloft, a detailed emissions inventory, and testing of a regional air quality model.

The report shows that the variability in sulfate concentrations was more strongly influenced by weather than by any other factor. It also shows that the maximum sulfur compound concentrations typically occur within 100–300 km of major sulfur dioxide emission sources.

The relative importance of various emission origins is given by source category and area for several substances, including sulfur dioxide and nitrogen oxides. Of the annual atmospheric pollutant burden over the SURE region, sulfur dioxide amounted to about 15%, nitrogen oxides about 20%, particulate sulfate and nitrate compounds less than 10%, other particulates about 15%, and ozone more than 40%.

The National Academy of Sciences has referred to the SURE research as the most reliable information on air quality in the Northeast. ■

CALENDAR

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

FEBRUARY

23–24
Heat Pump Research Update—Residential
New Orleans, Louisiana
Contact: James Calm (415) 855-8949

MARCH

6–7
Seminar: Indoor Air Quality
Atlanta, Georgia
Contact: Gary Purcell (415) 855-2168

14–16
Solar and Wind Power, 1984 Status and Outlook
San Diego, California
Contact: Edgar A. DeMeo (415) 855-2159

APRIL

9–11
3d International Retran Meeting
Las Vegas, Nevada
Contact: Lance Agee (415) 855-2106

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Vice President

MOLTEN SALT SOLAR-THERMAL SYSTEMS

Despite the encouraging technical performance of the Solar One 10-MW (e) experimental pilot plant near Barstow, California, during the past 18 months, U.S. solar-thermal central receiver development currently faces much uncertainty. Changes in federal strategy for renewable energy development have caused government programs to move away from field installation and testing in favor of longer-term research. However, the remaining technical and business risks are sufficiently high that private industry shies away from investing several hundred million dollars to build the larger installations necessary to quantify scale economies in power plant turbine generator facilities, production of key solar components, and power plant operating and maintenance requirements. EPRI's solar-thermal program has recently been reoriented to reflect the overall shift in national priorities. The Institute had been developing next-generation central receiver hardware as a logical follow-on to the current-generation hardware development originally supported by federal funds. In the past 18 months, however, EPRI activities in central receivers have focused on documenting, evaluating, and encouraging field tests already under way and on hardware testing and development activities that enjoy a broad base of interest, support, and cofunding from the utility and industrial communities. Several efforts of the first type are now under way with EPRI funding and will be discussed in future status reports. This report discusses the key activity in the second category: the design, construction, test, and evaluation of a complete central receiver solar electric power generation system that uses molten nitrate salts as the heat transfer and energy storage medium.

Despite technical results that offer encouragement for continued development, financial barriers have placed the national central receiver program in a holding pattern. Compounding the problem for those wishing to move forward are impediments faced by all renewable energy technologies, such as the generally depressed economy, apparent stability in prices for conventional fuel, and uncertainties in future requirements for new electric power generation capacity. Nevertheless, a nucleus of industrial, utility, and government organizations remains committed to continued development of solar central receiver power systems. This commitment stems from a belief that despite the lack of risk-reducing modularity enjoyed by some other renewable energy technologies, central receiver systems may ultimately offer operational advantages leading to higher energy values and greater generation capacity credits.

Against this backdrop, EPRI's solar-thermal program has undergone a major redirection over the past 18 months. When the federal program emphasis shifted, testing and development efforts with present-generation approaches were endangered. EPRI activity in central receivers was therefore directed away from advanced hardware development and toward support of efforts to maintain and evaluate field testing already under way. For example, Burns & McDonnell Engineering Co. evaluated and documented the experience and lessons learned with Solar One during design, construction, and early startup (EPRI AP-3285). Honeywell, Inc., recently began an evaluation of operator reaction to Solar One's state-of-the-art digital control system. Both of these efforts are being conducted with considerable participation from the lead utility at Solar One, Southern California Edison Co. In a third activity, Rockwell International is helping Georgia Power Co. define a test program for a distributed-collector, point-focus dish system at Shenandoah, Georgia.

Solar-thermal central receiver systems have been under development since the early 1970s. The first systems constructed and tested used water-steam as the receiver's heat transfer fluid. Subsequent studies and test programs showed that molten salt, liquid sodium, and hot air possess

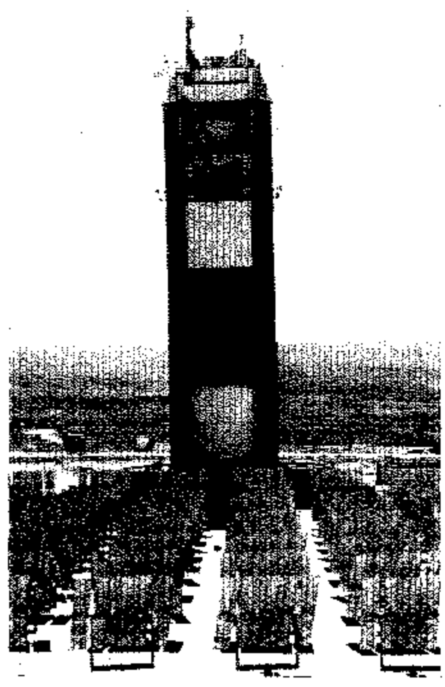


Figure 1 Martin Marietta Corp.'s 5-MW (th) molten salt receiver was successfully tested at DOE's CRTF in 1980.

certain advantages over water-steam, but many investigators feel that molten nitrate salt is the most promising heat transfer fluid, particularly for utility-scale electric power plants with thermal storage.

A group of 11 private organizations, DOE, and a government laboratory are building a $5 million molten salt electric experiment (MSEE) designed to verify the technical feasibility of using non-phase-changing molten nitrate salts (60% sodium nitrate, 40% potassium nitrate) in a solar-thermal central receiver system for electric power generation.

The site for the experiment—sized at 750 kW (e) and 5 MW (th)—is DOE's Central Receiver Test Facility (CRTF) at Sandia National Laboratories (Albuquerque). MSEE has three major objectives.

- To verify with a molten salt system the capability, flexibility, and simplicity of an advanced central receiver concept
- To provide performance information and operating experience on the system for utilities, system designers, hardware suppliers, and the financial community
- To establish a test bed for the future development of components and advanced control systems

The project is proceeding in two phases. Phase 1, nearly complete, includes design, construction, installation, checkout, and verification. In Phase 2, teams of utility and industry personnel will operate and test the system for approximately six months. In a potential third phase, the system may be run for an additional 2½ years either as-is or modified to incorporate and test new components.

Martin Marietta Corp., with DOE support, has already built the receiver (Figure 1) and thermal storage unit (Figure 2) as subsystem research experiments, although the salt-loop piping that interconnects the storage tanks and the receiver, along with associated pumps, valves, and controls, is new hardware (Figure 3). The tower and heliostat field to concentrate solar energy onto the receiver are already available. A specially designed and built molten salt steam generator is now ready, and project participants have purchased and installed a used 750-kW (e) turbine generator to convert thermal energy to electricity, which will be fed into the Kirtland Air Force Base power grid. The heat rejection subsystem, part of CRTF, has been used in previous test programs. The master control subsystem for the complete experiment is new.

It is expected that MSEE will demonstrate

Figure 2 The thermal storage subsystem, successfully tested in 1981–1982 at CRTF, includes a hot salt tank (left) and a cold salt tank (right).

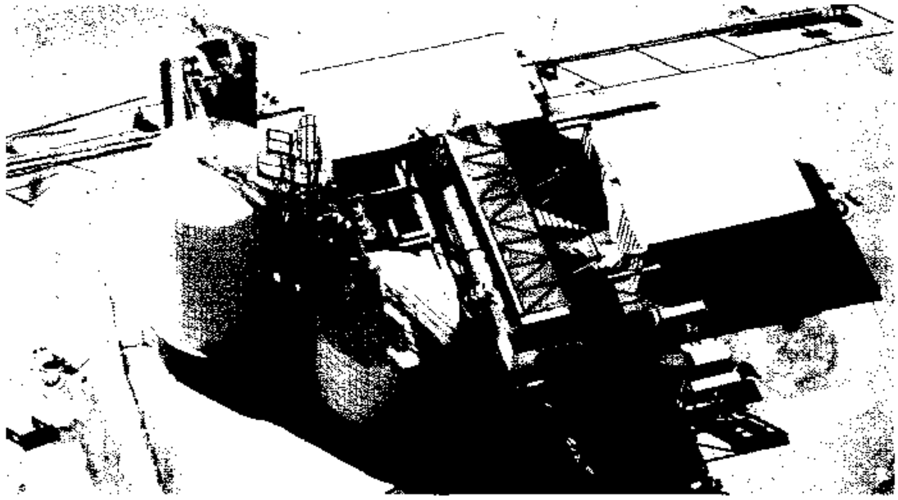


Figure 3 Salt-loop piping interconnects the receiver and storage subsystems. The molten salt steam generator is adjacent to the cold salt tank.

the advantage of an advanced central receiver concept. Because the thermal storage decouples the receiver-to-storage salt loop from the water-steam loop in this system, complicated controls are not necessary to protect the turbine generator and other steam-side components from variable steam conditions caused by cloud transients. MSEE will also demonstrate and develop operating procedures for three modes of system operation: storage charging only, steam generation only, and simultaneous charging and steam generation. Through their hands-on experience in the design and operation of MSEE, potential suppliers and users are expected to gain increased confidence in the central receiver concept in general and in molten salt systems in particular. Moreover, as a test bed for future component development, MSEE can support the testing of new advanced molten salt and sodium receivers now under consideration by industrial firms. An advanced automatic control system, to include heliostat control and automatic startup and shutdown features, is another possible extension that may allow remote or unattended operation of the system.

System description

The MSEE system converts solar energy to electricity, using molten salt and water-steam as the working fluids. The receiver, located at the top of the CRTF tower, receives concentrated solar energy from the collector field. Molten salt from a cold storage tank, located at ground level, is pumped up the tower piping and through the receiver. In the experiment, the cold-salt design point temperature is 306°C (580°F). The salt is heated from 306 to 566°C (580 to 1050°F) in the receiver, flows through a downcomer, and is throttled into the hot-salt storage tank. The hot-salt design point temperature is 566°C (1050°F). Hot salt from storage is pumped through the steam generator superheater and evaporator and then returns to the cold storage tank. The injection of an additional flow of cold salt in the salt line between the superheater and evaporator reduces the temperature of the salt entering the evaporator; this practice allows the use of low-alloy steel in the evaporator. Main steam from the steam generator drives a conventional steam turbine generator.

The molten salt receiver system has two principal advantages over a water-steam receiver system: the thermal storage subsystem decouples the steam generator and turbine from the receiver; and molten salt from the receiver serves as the thermal storage fluid, thus providing an inexpensive source of thermal storage and a constant-temperature heat source for the steam generator. Table 1 shows key technical characteristics of the MSEE system.

Project participants and schedule

Table 2 lists the companies providing funds, in-kind services, and operating and engineering personnel for Phase 2 of MSEE. All the industrial firms shown are contributing in-kind services. In addition, all sponsors are participating in a management structure designed to integrate participants' needs and objectives.

The three-member Executive Committee (a DOE representative as chairman, one utility representative, and one industry representative) establishes overall policy and provides management oversight for the experiment. This committee accepts recommendations from the Sponsors Committee and the Technical Committee, and it directs the project manager in the design, construction, and operation of the experiment.

The Sponsors Committee coordinates industry-utility-government interests, and the Technical Committee provides technical advice on the experiment's design, construction, and operation. All MSEE participants have representatives on these two committees.

During Phase 1, Sandia (Livermore) is the project manager, and Martin Marietta Corp. is the key subcontractor responsible for sys-

Table 1
MSEE OPERATING CHARACTERISTICS

Component	Characteristics
Heliostat field (existing)	221 heliostats
	Mirror surface: 400 ft² (37 m²) each
Tower (existing)	Concrete
	200 ft (61 m) high
	Internal lifting module
Master control	EMCON D-2 distributed digital control system
	Central consoles
	Separate unit protection system
Receiver (refurbished)	Rating: 5 MW (th)
	Salt temperatures: 306°C (580°F) in, 566°C (1050°F) out
	Configuration: cavity with door
	Absorber: single panel of ¾-in Incoloy 800 tubes (18 passes, 16 tubes per pass)
	Peak flux: 630 kW/m² (100,000 Btu/h · ft²)
Thermal storage (existing)	Rating: 6.54 MWh when operating between 306°C and 566°C
	Two-tank type (hot tank with internal insulation, cold tank with external insulation)
Steam generator (new; B&W commercial prototype)	Forced recirculation system
	Evaporator and superheater (both U-tube and U-shell) with steam drum separator
	Rating: 11,000 lb/h steam at 504°C (940°F) and 1100 psi (7.6 MPa); 3.13 MW (th)
Turbine generator (rebuilt General Electric Co.)	Marine turbine
	Rating: 750 kW (e)
Heat rejection and feedwater system (existing)	Feedwater treatment only
	Storage: 20,000 gal (90 m³) demineralized water
	Dry-cooling capacity: 7 MW (th)

Table 2
MSEE PARTICIPANTS

Industrial Organizations	Function
Martin Marietta Corp.	System integrator Master controls Refurbished receiver
Black & Veatch Consulting Engineers	Salt piping design Steam piping design Site support for construction
Babcock & Wilcox Co.	Steam generator
Olin Corp.	Molten salt analysis and corrosion tests; funds contributor
McDonnell Douglas Corp.	Phase 2 plans and implementation Experiment evaluation and documentation
Foster Wheeler Solar Development Corp.	On-site engineering support
Utilities	
Arizona Public Service Co.	Funds contributor; operating team
Pacific Gas and Electric Co.	Funds contributor; operating team
Public Service Co. of New Mexico	On-site support; operating team
Southern California Edison Co.	Funds contributor
Electric Power Research Institute	Funds contributor; Phase 2 project management
Government	
U.S. Department of Energy	Funds contributor; site owner
Sandia National Laboratories	Project management; site operator
Arizona Solar Energy Commission	Project initiation support

tem integration. EPRI has responsibility for the Phase 2 test and operations effort, with McDonnell Douglas Corp. as key contractor. Throughout both phases, Sandia (Albuquerque) is responsible for site management and facility operation at CRTF. Construction and subsystem-system checkout testing are now nearly complete. Sandia (Albuquerque), McDonnell Douglas, and each of the operating teams residing at CRTF will carry out the Phase 2 test and operating plan, with assistance from other project participants. Public Service Co. of New Mexico is providing the first test and operations team for Phase 2, which is to begin shortly. McDonnell Douglas will document and evaluate MSEE system performance as part of its responsibilities under contract to EPRI. Of particular interest are such issues as energy and power production characteristics; comparisons between predicted and actual performance; scale-up information; operator response; parasitic losses; and integrity of the system, subsystems, components, and the molten salt heat transfer medium. Advanced subsystem and component tests may also follow, again as cooperative, cofunded efforts by DOE and major industrial firms involved in continued central receiver development efforts. *Program Manager: Edgar A. DeMeo*

U.S. COAL TESTS IN SHELL PILOT PLANT GASIFIER

The Shell coal gasification process (SCGP), under development for the past decade, features a pressurized, slagging, entrained-flow reactor fed with dry pulverized coal and oxygen. Therefore, it has the potential to gasify efficiently a wide range of coals, especially low-rank coals (e.g., lignite) with high moisture content. A 6-t/d pilot plant has been operating since 1976 at the Royal Dutch Shell International Research Laboratory, Amsterdam (KSLA), and a larger, 150-t/d plant has logged over 6000 hours at the Deutsche Shell refinery at Harburg (near the city of Hamburg), West Germany. These units have used primarily European coals. This study, undertaken jointly with Shell Oil Co. (USA), evaluated two American coals in the SCGP pilot plant for possible electric power applications in the United States.

Project description

EPRI selected an Illinois basin, high-sulfur bituminous coal and a Gulf Coast lignite for the pilot plant tests. A 10-day experimental program was planned for each coal to determine its steady-state performance over a range of operating conditions. Included were three scouting periods of 24 hours each at different oxygen-coal ratios, plus a fourth with steam addition, followed by a long run of 96 hours at steady conditions. The program also included a test of transient operation and part-load performance, accomplished by shifting from the normal two-burner operation to single-burner operation for 24 hours at 50% capacity. The program concluded with a 24-hour high-pressure test at 30 bar (3 MPa) to provide a contrast with the preceding runs at 20 bar (2 MPa).

The initial test run took place in December 1981, using a washed coal from the Illinois No. 5 seam at Midland Coal Co.'s Rapatee mine in Fulton County, Illinois. A U.S. vendor ground and dried the coal and loaded it into 74-ft^3 (2.1-m^3) aluminum tote bins for ocean transport to Amsterdam. However, problems arose in feeding this batch into the pilot plant because the coal did not uniformly meet specifications, varying in particle-size distribution from bin to bin.

A second batch of washed coal (1¼-in × 0 nominal size) from the Midland mine was transported to Europe in 35-ft (11-m) cargo containers, this time to be prepared by Industriekohle GmbH (IKO) in West Germany. The 17% moisture content of this coal exceeded the vendor's capacity to dry the coal, resulting in a different moisture level (varying from 8.5 to 12.1%) for each coal lot from this batch. However, IKO was able to grind the batch uniformly to the specified particle-size distribution (Figure 4).

The test using the second batch of Illinois coal ran successfully in June 1982. Complete test results for both batches of Illinois coal appear in the final report (EPRI AP-2844, Vol. 2), including size analysis and composition of coal from different bins or lots in both batches.

The next series of tests used a run-of-mine lignite acquired from the Wilcox group deposit in Texas. Another U.S. vendor ground and dried the coal in a Williams fluid-bed roller mill, reducing moisture from about 30 to 12.4 wt% (at mill outlet temperatures of 118°C). The highly reactive lignite was then placed in 74-ft³ (2.1-m³) tote bins, purged with nitrogen, and loaded in cargo containers aboard ship. The Texas lignite was successfully run as planned in September 1982. Complete results of the lignite tests are presented in the final report (AP-2844, Vol. 1).

The pilot plant process

The first step in the SCGP pilot plant (Figure 5) is removal of coarse coal or refuse from the pulverized coal, using a vibrating screen with 1-mm openings. The coal is then pressurized in a lock hopper system for pneumatic transport to the reactor via two diametrically opposed fired burners. The carrier gas in the pilot plant is typically nitrogen, although, in principle, use of recycled product gas is also possible to reduce the nitrogen content (roughly 15% by volume) of the medium-Btu product gas and correspondingly increase the gas heating value.

A flame reaction with oxygen, sometimes with steam as a moderator, partially oxidizes the coal. Reactor temperatures are sufficient to convert a major portion of the ash to a molten slag. The slag then leaves the reactor through a slag tap and falls into a water bath, forming dense, glassy, nonleachable, solid slag particles. In the small pilot plant reactor, some deentrained fly ash (fine ash particles and unconverted carbon) pass through the slag tap. (Note: Although not part of these tests, negligible amounts of bottom char have been experienced with the larger reactor at the Harburg refinery, which has gasified mainly European coals.)

Reactor product gas with fly slag carried overhead is quenched with recycle product gas to a temperature of 350°C. A cyclone then separates most of the fly slag by dry sluicing the slag from the bottom. An economizer, itself cooled with recirculating water, partially cools the cyclone overhead gas stream. A wet scrubbing system, using both a venturi scrubber and a packed-bed scrubber, finally separates the remaining solids from the gas stream so that the syngas product leaves the scrubber system free of solids (less than 1 mg/m³, standard conditions). Part of the product gas recycles through a compressor to the quench section above the gasifier.

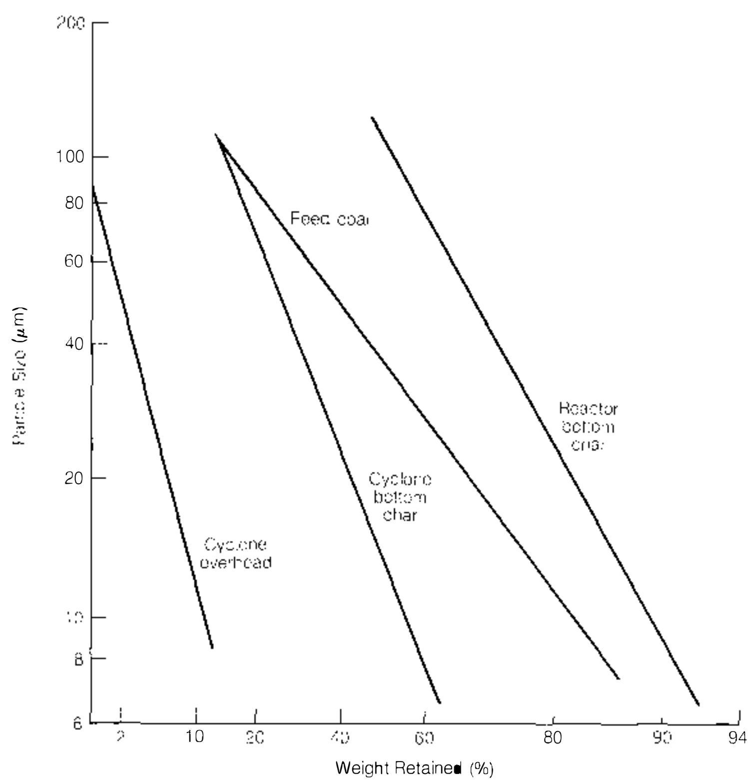


Figure 4 Typical particle-size distributions for the feed coal and char effluents during gasification of Illinois No. 5 bituminous coal in the 6-t/d Shell pilot plant gasifier.

Test results

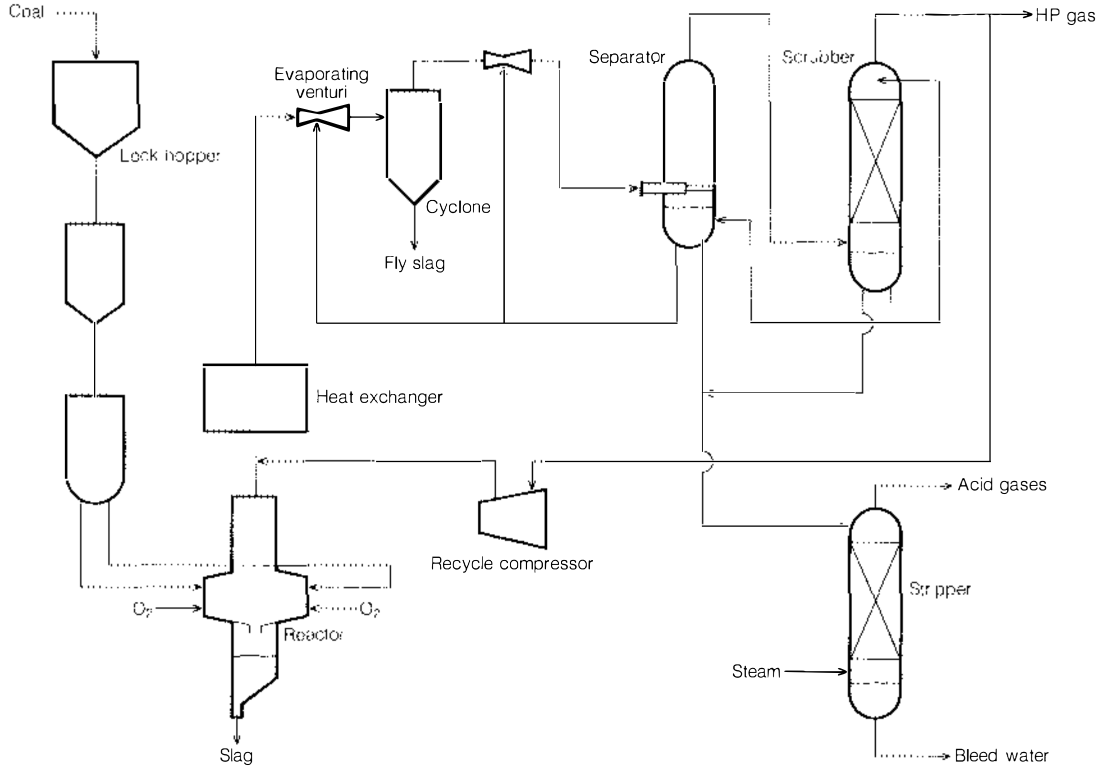
The first batch of Illinois coal had a low moisture content (1.5–5.0 wt%) and the gasifier run proceeded for only about 60 hours because of the poor coal feed characteristics mentioned above. However, using a second batch of 80 tons, the planned test program was successfully completed during 330 hours of operation. This batch had a relatively high and varying moisture content (7–12 wt%). No coal feeding problems occurred with this batch, slag flow was normal, and the slagging operation was comparable to that with other bituminous coals. The high moisture content eliminated the need for steam addition.

For most of the test, coal throughput was 150 kg/h (moisture- and ash-free, or maf), and the pressure was 21 bar (2.1 MPa). Varying the oxygen-coal (maf) mass ratio from 0.9 to 1.04 had the following results.

- Carbon conversion increased from 86 to 99% (Figure 6).
- Reactor outlet temperature rose from 1280 to 1500°C.
- Relative heat loss through reactor walls increased from 4.4 to 7% of the coal energy value (i.e., lower heating value, or LHV).
- Cold-gas thermal efficiency increased from 69 to 74.5% of the coal energy value (LHV).

At lower coal moisture levels (less than 4.8%), thermal efficiencies greater than 76% were achieved at an oxygen-coal ratio of 0.98. At similar oxygen-coal ratios, lower coal moisture content also produced higher values of carbon conversion, syngas yield, and thermal efficiency. However, these differences became negligible as the oxygen-coal ratio approached 1.00. For the low-moisture feed, reactor temperature was consistently higher (by 100–150°C), and

Figure 5 The Shell coal gasification process. In a joint project, EPRI and Shell Oil Co. (USA) evaluated two American coals, a high-sulfur bituminous and a Gulf Coast lignite, in a 6-t/d pilot plant.



the carbon dioxide content of the product gas was consistently lower. A pressure increase from normal operation at 20 bar to 29 bar (2 MPa to 2.9 MPa), with coal throughput increased to 133% of its normal value, had no major observable effects.

The run at 50% capacity required about a 5% increase in oxygen-coal ratio to achieve carbon conversions of 87.5–90.5%, primarily because of the increase in relative heat loss. Thermal efficiency dropped from 74% to about 68%, and the temperature fell from more than 1400°C to 1200°C or less as relative heat losses from the reactor increased from under 7% to roughly 10%.

Transient response tests varied coal throughput by 50% by turning off one burner; this operation had virtually no effect on reactor pressure, and the product gas flow rate responded in less than one minute to the new coal rate.

An extensive environmental sampling program during steady-state operation detected no priority pollutant organics above 1 ppb by weight in the aqueous effluent.

Results of the Texas lignite run were even more promising. The SCGP pilot plant successfully gasified 44 tons of the lignite during 222 hours of operation. Operation was virtually continuous, with only one brief interruption.

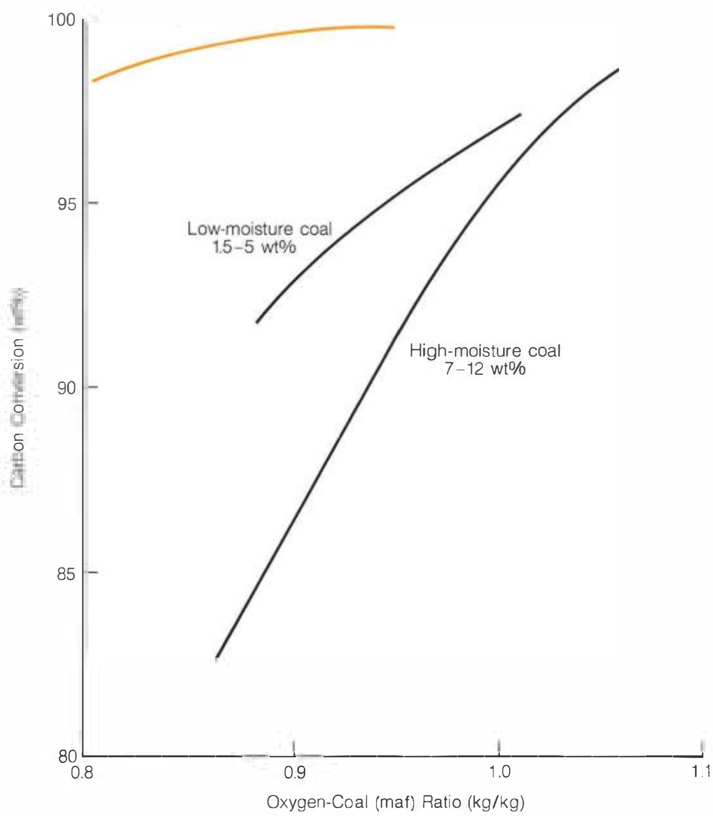
Coal feeding went smoothly, allowing stable operation of the overall pilot plant. The low viscosity of the slag from the process promoted liquid slag flow from the reactor, even at the mild operating conditions (e.g., low temperatures) that prevailed.

The oxygen-coal mass ratio was varied from 0.82 to 0.94 in a series of experiments (Figure 6) at an maf coal feed rate of 150 kg/h and a pressure of 21 bar (2.1 MPa). At an oxygen-coal ratio of 0.85 and a moderate outlet temperature of 1250°C, carbon conversion reached 99%, indicating that Texas lignite is indeed a highly reactive coal feedstock. Carbon conversion continued to increase at higher ratios as well, but above a ratio of 0.9, the reactor became "overfired," causing a sharp increase in outlet temperature, greater heat loss, and increased product gas CO_2 content. Syngas yield per unit mass of coal then decreased accordingly.

Cold-gas thermal efficiency reached a maximum of 76% at an oxygen-coal ratio of 0.9. Shell reports that the syngas yield at this optimal point is about 7% below that for a typical bituminous coal with a comparable thermal efficiency (77%). The difference in gas yield reflects the lignite's inherently higher oxygen content. Increasing the pressure to 28 bar (2.8 MPa) in a later test raised the thermal efficiency from 76 to 78%, reflecting a significant drop in reactor heat loss.

A subsequent test run lowered coal throughput to 50% capacity (one-burner operation), and another increased it to 133% capacity (200 kg/h maf coal). At these rates, modest changes were observed in outlet temperatures, heat loss, and product gas

Figure 6 The effect of varying the oxygen-coal (maf) mass ratio on carbon conversion of Illinois No. 5 bituminous (black) and Texas lignite (color) feed coals in the 6-t/d pilot plant.



CO_2 content; however, thermal efficiency changes were insignificant. During transient tests, the flow of product gas responded within one minute to a stepwise change in coal feed rate; unit pressure and operability showed negligible changes following the feed transient.

In the environmental sampling effort, detailed data were collected on the distribution of major elements and trace components in gaseous, solid, and liquid effluent streams. This was done during a demonstration run that recirculated bleed water from the venturi scrubber to investigate buildup effects in the water recycle loop. The sampling showed no priority organic pollutants above 1 ppb by weight in the aqueous effluent.

Implications for scale-up

A large commercial SCGP plant would be designed differently than the pilot plant, which has characteristics unique to a small-scale unit. For example, in the Amsterdam reactor the coal is in dilute phase during pneumatic transport, resulting in a rather large carrier gas flow (e.g., 0.4 kg/kg maf coal for Illinois No. 5). Dense-phase pneumatic transport in the larger unit at Harburg, on the other hand, has reduced carrier gas to about one-fourth that amount. Moreover, replacing the nitrogen in the carrier gas with product gas will further reduce the inert material and improve thermal efficiency.

In the small reactor, heat losses through the walls are large because of a high surface-to-volume ratio for heat transfer. In a larger unit, heat losses would be lower, and water-wall construction would allow the remaining wall losses to be converted to steam energy. Bottom char would also be negligible in a larger plant.

The overall differences in a large-scale plant design should lead to higher carbon conversion at slightly reduced oxygen consumption. As a result, thermal efficiency is expected to increase 3% in a commercial unit.

Research benefits

Low-rank coals generally have a lower energy value than bituminous coals because of their higher ash, moisture, and oxygen content and correspondingly lower carbon content. The Shell project has shown SCGP to be potentially effective for gasifying these low-rank and relatively low-cost coals found in abundance in the southern and western United States.

Before this project, the SCGP pilot plant had mainly processed European coals, including German brown coals, which are different from U.S. lignite. However, the Texas lignite performed extremely well, with high carbon conversion rates and high thermal efficiencies at moderate conditions, as well as smooth coal feeding and slagging operations. The Illinois bituminous coal performed as well as bituminous coals tested previously in the SCGP pilot plant. It showed reasonably high conversion levels and thermal efficiencies at somewhat higher temperatures and with slightly higher oxygen demand than the lignite (which inherently has higher oxygen content). Accordingly, both coals qualify as very good feedstock for the SCGP, making it a leading alternative for gasifying a wide range of U.S. coals for electric power applications. Shell Oil Co. (USA) is actively seeking utility industry participation in projects based on this technology. *Project Manager: George Quentin*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

HEAT REJECTION

This article summarizes the R&D efforts currently under way or being planned by the heat rejection subprogram of the Heat, Waste, and Water Management Program. All the main types of cooling systems used in steam-electric power plants are addressed: evaporative cooling towers and water-conserving towers (previously reported on in the October 1982 issue of the EPRI Journal, *p. 39), once-through cooling systems, and cooling ponds.*

Evaporative cooling towers

In response to the increasing use of conventional evaporative cooling towers in new plants, much of the work of the heat rejection subprogram focuses on this technology. One important area of R&D activity involves the prediction, measurement, and improvement of wet tower thermal performance. A second main area of activity involves methods for predicting and measuring the physical distribution of cooling-tower emissions in the environment, primarily the visible exhaust plume and associated drift deposition.

By improving the thermal performance of evaporative cooling towers, significant improvements in power plant efficiency and economics can be achieved. A major EPRI research effort in this area (RP2113) is the construction of a pilot-scale facility for evaluating the thermal performance characteristics of different types of cooling-tower fills and fill configurations. (Cooling-tower fill is the extended surface on which heat and mass transfer between water and air takes place.) The facility, shown in Figure 1, is designed to provide easy access for changing fills and configurations in sections that simulate crossflow or counterflow operation. Engineering work has been completed, and construction of the facility is under way at the W. A. Parish station of Houston Lighting & Power Co. Testing of selected fills is scheduled to begin next spring and to continue until at least 1985. Similar fill testing will be conducted concurrently in dedicated cells of full-scale cooling towers to obtain validation data.

The three-year test facility project is funded jointly by EPRI and a group of utilities consisting of Houston Lighting & Power Co., Indianapolis Power & Light Co., Pacific Gas and Electric Co., Public Service Co. of Oklahoma, Southern California Edison Co., Southern Company Services, Inc., and the Tennessee Valley Authority. Other project participants are being sought. The principal contractors are Battelle, Pacific Northwest Laboratories; Environmental Systems Corp.; and TVA (Norris Engineering Laboratory).

In a related effort, data collected from the facility will be used to validate and improve the predictive capabilities of VERA2D, a computer model developed under RP1262 for the two-dimensional analysis of flow, heat transfer, and mass transfer in evaporative cooling towers. An updated and extended version of the VERA code (which was introduced in FP-1279), VERA2D is capable of analyzing mechanical- and natural-draft cooling towers of crossflow or counterflow design. Because it does not rely on many of the simplifying assumptions used in other available models, VERA2D represents a significant step toward the comprehensive analysis of cooling-tower performance. The code

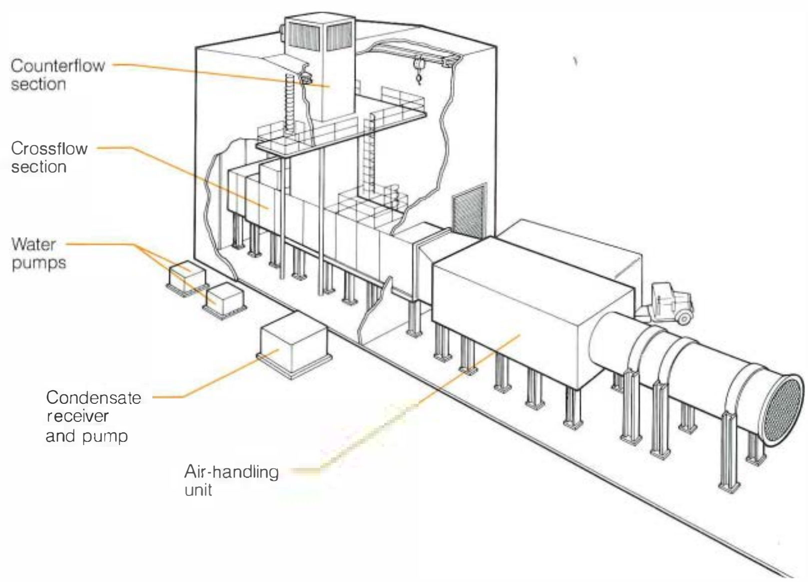


Figure 1 This small-scale test facility for measuring the performance of cooling-tower fills is under construction at the Parish station of Houston Lighting & Power Co. Full-scale fill tests are also planned.

is available through the Electric Power Software Center and is summarized in a two-volume EPRI report issued earlier this year (CS-2923).

Other advanced numerical models for predicting cooling-tower performance will be used to analyze experimental data from the pilot facility as well. These include a computer code developed by TVA that provides accurate predictions with small computing costs; TVA is preparing a report on this model. Also to be applied is the TEFERI code, developed by Electricité de France (EDF) on the basis of a method formulated at the University of Hannover (Federal Republic of Germany). In a validation study by EDF that used full-scale test results, this code proved to be accurate and economical. Two EPRI special reports on TEFERI have been issued; one presents the code listing and a user's manual (CS-3212-SR), and the other summarizes the EDF validation work (CS-3144-SR).

In connection with the goal of improved thermal performance for evaporative cooling towers, EPRI is considering projects to address fill deterioration and tower icing. According to a recent survey by TVA, 79% of utility cooling towers show some degree of fill deterioration, and 81% experience problems with icing, which can contribute to fill deterioration and reduced thermal performance.

One proposed EPRI effort would be to expand the TVA survey to better define these problems. Fill deterioration research is under consideration to investigate the causes and rates for different fill types, the impact of deterioration on overall thermal performance, and potential corrective actions. The results of such research would supplement information from RP2113 in helping utilities select cooling-tower fills. Research on cooling-tower icing problems would focus on ways to limit the amount of icing (work that might lead to the development of operating guidelines) and on methods for deicing, such as hot water bypass, fan shutoff or reversal, fill material or louver modifications, and water distribution changes.

The primary emphasis of the projects addressing wet tower performance is on the immediate needs and specific problems of utilities. The long-term goal is to develop overall guidelines for achieving improved thermal performance through bid specification and review, acceptance testing, and upgrade evaluation.

Research on the environmental impact of wet towers is concerned with the visible exhaust plume—which may cause ground fogging, icing, and shadowing—and with the deposition of saline drift droplets, which may damage vegetation and cause corrosion. In a multiyear effort (RP906) Argonne National Laboratory, in association with the University of Illinois and the University of Chicago, has developed a comprehensive computer code capable of accurately predicting visible plume trajectories and drift deposition patterns for single and clustered towers. A five-volume report (CS-1683) and an executive summary (CS-1683-SY) describing the model and its validation are available. A user's manual is being prepared.

In a related project (RP1260-11), the Massachusetts Institute of Technology performed a laboratory evaluation of various devices used to measure cooling-tower drift. Investigators from the United States, the Federal Republic of Germany, and Belgium tested devices in a wind tunnel at MIT, and the results were compared with those from a laboratory-standard device developed by MIT. A report that describes the standard device, a laser light-scattering system with optical detection and electronic signal processing components, is available (CS-3098).

As reported at the 1983 American Power Conference, the testing program found none of the available drift measurement techniques to be adequate over the entire range of conditions encountered in a wet cooling tower. Droplet-sizing devices (e.g., sensitive paper) are most effective for small droplets and low mass flow rates, while isokinetic and chemical assay techniques are most accurate under high-load, large-droplet conditions. A final report summarizing the test results and data analysis is being prepared.

Water-conserving systems

To minimize the cost impact when conditions require utilities to specify water-conserving cooling systems, EPRI is sponsoring work to identify, evaluate, and demonstrate dry and wet-dry technologies that offer significant cost savings over commercially available technology.

The major effort in this area is the demonstration of an ammonia phase-change heat rejection system at the 10-MW (e) Advanced Concepts Test (ACT) Facility at Pacific Gas and Electric Co.'s Kern station (RP422). The project is cosponsored by PG&E, Southern California Edison Co., the Los Angeles Department of Water & Power, the Canadian Electrical Association, and the Salt River Project. Other utility participants are being sought. Operations and testing are being managed by Battelle, Pacific Northwest Laboratories, with assistance from Union Carbide Corp.

At the facility two air-cooled heat exchangers that feature water augmentation during peak load are being tested in conjunction with a steam condenser–ammonia reboiler with enhanced heat transfer surfaces. Also being tested is a capacitive cooling system that operates without water augmentation; this unit was designed and built by Chicago Bridge & Iron Co. A feature article in the May 1983 issue of the *EPRI Journal* reviewed progress at the ACT Facility, and a series of reports describing system design and testing is available. The reduced operation of the host station has delayed the test program, but results to date point toward commercial feasibility. (During the past year a 5-MW [e] ammonia phase-change loop was successfully put into commercial service near Calgary, Canada.) Extensive testing at the ACT Facility is planned for 1984.

EPRI has been cooperating closely in this area with EDF, which is now implementing a 20-MW (e) steam-ammonia bottoming cycle at the Gennevilliers station near Paris. The French system should be operational in 1984, with grid tie-in scheduled for January 1, 1985. EDF is also conducting studies of a bottoming cycle for use with a 1350-MW (e) pressurized water reactor. EPRI has published a special report on the functional principles of the 20-MW (e) EDF bottoming cycle (CS-3254-SR) and another on the compatibility of common construction materials and ammonia (CS-3148-SR).

In other work on water-conserving cooling (RP422-9 and -10), Public Service Co. of New Mexico; United Engineers & Constructors, Inc.; and Environmental Systems Corp. developed detailed management and program plans for a comprehensive test of the hybrid wet-dry cooling tower at the 466-MW (e) San Juan-3 plant near Farmington, New Mexico. Although the scope and schedule of the testing phase of this effort have not yet been determined, these documents have been published wth an executive summary (CS-3130) because of the useful planning information and cost data they contain.

Dynatech R/D Co. has evaluated the potential of nonmetallic materials for use in low-cost, corrosion-resistant, air-cooled power plant heat exchangers (RP1260-29). Research in Europe has already led to the successful commercial application of smooth-tube plastic heat exchangers. In the current phase of the EPRI project, Dynatech has identified enhanced tube configurations (e.g., a low-profile fin) that show promise for substantial performance and cost improvements over smooth tubes. A report on this effort is in press. Project development plans call for laboratory tests to verify the predicted performance of the enhanced configurations, as well as for discussions with manufacturers and utilities to explore the demonstration of an advanced plastic heat exchanger at a power station to establish commercial feasibility.

Once-through cooling

Efforts on open-cycle (once-through) cooling seek to minimize the entrainment and entrapment of aquatic species at acceptable costs. The objective of one current project (RP2214-1) is to collect and make accessible the vast body of diverse data available on intake structures. Using a methodology developed in a pilot study (EA-2127), Tetra Tech, Inc., is surveying utilities on all relevant aspects of intake structures—including biologic performance, hydraulic performance, cost, maintenance, and current research. To date, 86% of the preliminary questionnaires have been returned, and 60% of the utilities contacted have returned at least one section of the comprehensive follow-up questionnaires, which indicates that the data set will be substantial. In addition to a computerized data base for easy access, the results will be available as hard copy.

Plans for research on open-cycle cooling systems call for the pilot-scale testing of promising intake structure designs in several biologic environments (Figure 2). EPRI is consulting with an informal utility working group to develop this project. To aid in project scoping, Stone & Webster Engineering Corp. is assembling information on available intake structure research facilities and is cooperating with EPRI and the working group in developing a methodology for ranking the facility options (RP2214-2). Publication of a manual on intake structure research facilities is planned.

Cooling ponds

Current R&D activities in this area are aimed at improving pond thermal performance prediction capabilities and pond design. Under RP1260-17 MIT—in association with the Nuclear Regulatory Commission; Battelle, Pacific Northwest Laboratories; Clemson University; the Alden Research Laboratory of Worcester Polytechnic Institute; and the University of Miami—investigated ways to improve the prediction of evaporative losses from cooling ponds. It was found that evaporation rate data can be correlated with acceptable accuracy by using mathematical models (CS-2325).

On the basis of these positive results, MIT is currently performing laboratory tests and computer simulations aimed at improved pond design (RP2385). In addition, a field test program by MIT and several other organizations at the Savannah River Project is being planned. The high water temperatures and unique pond geometries at this site make it ideal for obtaining supplementary data that can be used to improve algorithms for predicting pond performance. *Subprogram Manager: John A. Bartz; Project Manager: Wayne C. Micheletti*

FGD COST UPDATE

The high cost of flue gas desulfurization (FGD) equipment for coal-fired power plants is a major issue facing electric utilities. The FGD system is one of the most expensive plant subsystems; for a new plant, the capital cost for FGD is exceeded only by the cost of the boiler itself. Further, the maintenance cost for the FGD system (expressed as a fraction of initial capital investment) is 2 to 20 times the maintenance cost for the rest of the plant. Thus it is important for utilities to have accurate, up-to-date information on the capital, operating, and maintenance costs of commercially important FGD options. To this end EPRI's Desulfurization Processes Program routinely sponsors projects to update FGD system costs. The most recent of these has been completed, and a final report will be published shortly (CS-3342).

In this project Stearns-Roger Engineering Corp. evaluated the capital and operating costs of 16 FGD systems. Table 1 summarizes

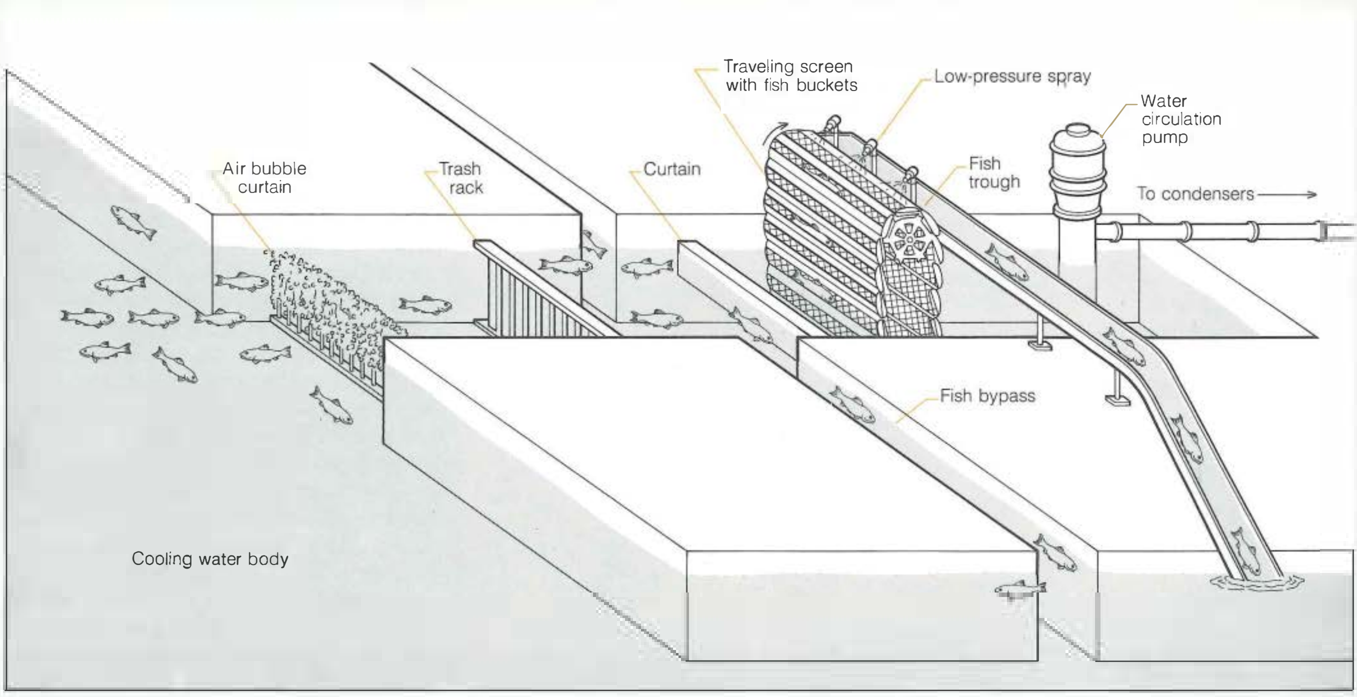


Figure 2 Power plant intake featuring two avoidance curtains and a modified traveling screen to minimize the entrainment and entrapment of aquatic species. EPRI is working with utilities on a test program to evaluate intake designs and technologies for this purpose.

the levelized busbar costs and capital costs for these systems. The processes are ranked in three categories: processes applicable to high-sulfur coal and producing a by-product for disposal (throwaway); processes applicable to low-sulfur coal and producing a throwaway by-product; and processes applicable to high-sulfur coal and producing a marketable sulfur or sulfuric acid product (regenerable).

The rankings in Table 1 must be interpreted cautiously. In certain situations the EPRI economic and process design premises can favor one process over another, and the use of different premises could change the results.

Methodology and assumptions

It is difficult to publish up-to-date, consistent FGD cost estimates because the relative costs of the various systems shift rapidly. Cost estimates can quickly become obsolete as a result of changing regulations, technological advances by utilities and their suppliers, laboratory and pilot plant R&D, demonstrations, and commercial operating experience. Further, economic analyses from different sources are usually based on different premises, which makes direct comparisons between analyses misleading. To minimize these differences and promote consistency of results from case to case and from project to project, EPRI has developed process design and economic evaluation criteria that are applicable to all FGD processes.

The process design criteria include the following.

- Generating-plant characteristics
- Coal and flue gas properties
- SO_2 removal requirements
- Boiler capacity
- General equipment requirements
- FGD system battery limits
- Raw material composition and requirements
- Waste disposal requirements

All the process design criteria used in the Stearns-Roger study are based on the incorporation of FGD systems into two new 500-MW generating units for a hypothetical power plant near Kenosha, Wisconsin. In the case of wet FGD systems, it is assumed that a separate particulate removal device is located upstream of the system. In the case of dry FGD systems, it is assumed that a fabric filter is located downstream of the system to remove particulates and FGD reaction by-products. All the costs summarized, however, exclude the cost of particulate control.

The coals used for the study are two reference coals described in the EPRI *Technical Assessment Guide:* a deep-mined, high-sulfur (4.0%) Illinois bituminous coal and a strip-mined, low-sulfur (0.48%) Wyoming subbituminous coal. The FGD systems are designed for compliance with federal New Source Performance Standards: a 90% overall reduction in potential SO_2 emissions for the high-sulfur coal and a 70% overall reduction for the low-sulfur coal. These removal efficiencies are based on a 30-day rolling average.

The study assumes a base case net plant heat rate of 9565 Btu/kWh for the plants fired with high-sulfur coal and 9999 Btu/kWh for those fired with low-sulfur coal. The heat rates include a 6% allowance for plant auxiliaries. Steam and power usages were developed for each FGD process and were added to the base case heat load in each system evaluation.

Certain equipment requirements are common to most or all the FGD systems evaluated. For example, the cost estimates developed for all the wet systems include the cost of reheating the saturated gas leaving the scrubber by 50°F (28°C). It is assumed that ambient air heated by cold reheat steam is used for this purpose. The costs for dry (powdered-reagent injection) and semidry (spray drying) systems do not include reheat.

All the systems considered in this study have both an induced-draft fan and a booster fan. The two operate simultaneously to provide the required draft pressure for the boiler and the particulate removal device, as well as to meet the FGD system pressure requirements. Fan capital and operating costs for the FGD system are calculated by using a ratio of the FGD system pressure requirements to the total pressure requirements of the power plant.

The FGD systems evaluated feature some equipment redundancy to increase reliability. Spares are assumed for FGD equipment whose loss would require immediate system shutdown. Complete redundancy is assumed for pumps in cases where the loss of one pump would require shutdown. No spares are assumed for such items as tanks, bins, silos, agitators, fans, and heat exchangers.

The establishment of consistent FGD system battery limits (i.e., system boundaries) is probably the most critical decision to be

Table 1
FGD PROCESS COST ESTIMATES

Process	Levelized Busbar Cost (mills/kWh)	Capital Cost ($/kW)
Throwaway, high-sulfur coal		
Chiyoda Thoroughbred-121	14	140
Dowa	14	173
Forced-oxidation limestone slurry	16	177
Saarberg Holter (lime)	16	132
Limestone dual alkali	16	162
Lime dual alkali	17	147
Conventional limestone slurry	18	175
Lime slurry	20	163
Throwaway, low-sulfur coal		
Lime spray drying	7.4	111
Conventional limestone slurry	7.8	109
Nahcolite injection	8.1	27
Regenerable, high-sulfur coal		
Magnesium oxide	19	269
Sulf-X	20	295
Wellman-Lord	26	274
Flakt-Boliden	29	391
Aqueous carbonate	30	401
Conosox	45	431

made in developing system costs. Battery limits must be defined in order to determine the equipment requirements of each process and the resulting cost impacts. Seemingly minor variations in the battery limits of an FGD system can dramatically affect the calculated capital and operating costs; therefore, comparing cost estimates for systems that have different battery limits can yield misleading results and inappropriate rankings.

One problem in defining FGD system battery limits and estimating costs is that the system shares many areas with the particulate removal system. To separate FGD and particulate removal costs, Stearns-Roger followed a systematic methodology. First, the cost of removing fly ash from the flue gas stream and disposing of it in a landfill was developed as a reference case (no FGD). Next, a combined FGD and particulate removal cost was developed for each FGD process considered. The reference case (particulate removal) cost was then subtracted from the combined FGD–particulate removal cost for each process to arrive at the FGD cost.

Waste disposal is accounted for in the costs of the FGD processes that yield a waste product. Identical disposal methods are assumed for identical waste products—for example, stacking for gypsum and landfill for sludge. Stearns-Roger developed the waste disposal subsystems on the basis of current technology and good engineering practices.

In the case of systems that yield a marketable by-product, the costs reflect a credit for the sale of that by-product. The assumed by-product is sulfuric acid for the magnesium oxide process and elemental sulfur for the other regenerable processes.

The economic criteria used in the FGD process evaluations were standardized to ensure consistent comparisons. Economic premises developed by EPRI (October 1, 1982, version) were followed in estimating and breaking down costs, which are presented in December 1982 dollars. A plant startup date of January 1, 1983, is assumed.

A levelized busbar cost was calculated for each FGD system. This cost consists of the variable and fixed operating costs and the levelized capital cost of each system. All costs assume an annual inflation rate of 8.5%, a discount rate of 12.5%, and a plant life of 30 years.

Results

Figure 3a shows the levelized busbar costs and their components—capital charges, fixed operating costs, and variable operating costs—for the throwaway processes for high-sulfur-coal application. Considering the variety of processes evaluated, the range

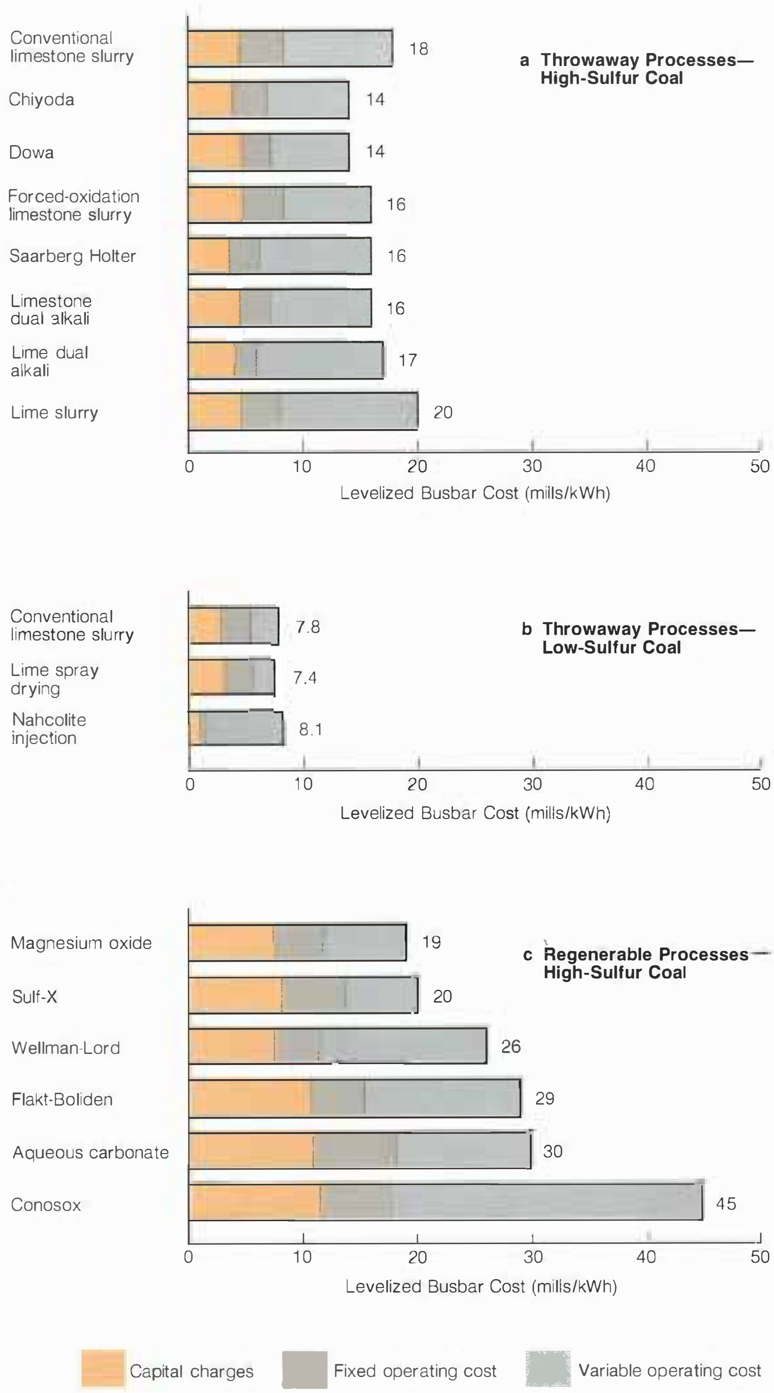


Figure 3 Levelized busbar costs and their components for 16 FGD processes evaluated by Stearns-Roger Engineering Corp. under RP1610-1. Of the throwaway processes (**a** and **b**), six are at the commercial stage of development; the exceptions are Chiyoda (full-size demonstration, 20–100 MW), Dowa (pilot plant), limestone dual alkali (bench scale), and nahcolite injection (demonstration). Of the regenerable processes (**c**), the magnesium oxide and Wellman-Lord systems are commercially available; the others are at the pilot plant stage.

between the lowest and highest levelized costs is rather small. Lime slurry scrubbing is the only process whose estimated cost is higher than that of conventional limestone slurry scrubbing. The cost difference between these two processes is primarily the result of reagent cost. Because lime is more expensive than limestone, the lime process has a higher variable operating cost. Equipment costs are similar for the two processes, as reflected in their approximately equal capital charges. Also, the processes' operating labor, maintenance, and by-product disposal requirements are similar; hence their fixed operating costs are nearly the same.

As illustrated in the figure, both dual-alkali processes have a slightly lower levelized busbar cost than conventional limestone slurry scrubbing. The reason is their use of a highly reactive, clear reagent scrubbing solution (sulfite), which results in lower capital charges and fixed operating costs. The limestone dual-alkali process is slightly cheaper than its lime counterpart, primarily because limestone is less expensive than lime. This difference in reagent cost is partly offset by higher capital charges and fixed costs for the limestone system because reagent preparation and regeneration are more expensive for limestone than for lime in a dual-alkali system.

At 16 mills/kWh, the forced-oxidation limestone slurry process is 2 mills/kWh less costly than conventional limestone slurry scrubbing. This is primarily because of its small variable operating cost—among the lowest for the high-sulfur-coal throwaway systems evaluated. Factors in this low cost are that the process uses a limestone reagent; that its low-volume, easily dewatered by-product does not require fixation; and that in most cases stacking can be used for disposal (assumed for this cost estimate).

The Chiyoda and Dowa processes have the lowest levelized busbar cost (14 mills/kWh) of the high-sulfur-coal throwaway systems considered. There are two basic reasons. First, their gypsum by-product is easy to dispose of; hence their variable operating costs are relatively low. Second, these recently developed processes are simpler and therefore potentially cheaper to build and maintain; hence their capital and fixed operating costs are relatively low.

Figure 3b compares the levelized busbar costs of three throwaway processes for low-sulfur-coal application: conventional limestone slurry scrubbing, lime spray drying, and nahcolite injection. The cost breakdowns show the proportion of the components to be similar for limestone scrubbing and lime spray drying. The estimated capital and fixed operating costs for these two processes are about the same; however, the limestone scrubber has a higher variable operating cost, resulting in a slightly higher total levelized cost. This is the opposite of what one would expect if only reagent costs were considered. It must be remembered that the reagent costs for a low-sulfur-coal case are only 10% of those for a high-sulfur-coal case. The variable operating cost is higher for limestone scrubbing because it includes reheat, higher energy requirements for slurry pumps and for gas-side pressure drop, and disposal of a high-volume sludge by-product.

The variable operating cost of the dry nahcolite injection process is quite high because of the plant site used in the evaluation. Kenosha, Wisconsin, is not near a source of nahcolite, and $104/t for rail transportation is included in the reagent cost of $140/t assumed for this process. If the plant site were close to the reagent source, nahcolite injection would be the cheapest of the three low-sulfur-coal throwaway processes evaluated. A sensitivity analysis indicates that a 50% increase or decrease in nahcolite cost results in a 40% change in the levelized busbar cost.

Because of its greater complexity, the lime spray-drying process has higher capital and fixed operating costs than nahcolite injection. Spray drying has the smaller variable operating cost of the two processes, however, because it uses a less expensive reagent, and produces a smaller amount of by-product for disposal (as a result of better reagent utilization).

Figure 3c presents the cost estimates for the six high-sulfur-coal regenerable processes evaluated by Stearns-Roger. These results indicate that for the Kenosha site the regenerable processes are generally not economically competitive with the throwaway processes. Only the magnesium oxide and Sulf-X systems show promise for competing with throwaway systems: at the Kenosha site, their levelized costs are comparable to that of lime slurry scrubbing.

The variable operating costs shown in Figure 3c include credits for the value of the marketable by-product. This value can vary widely, depending on local market conditions and transportation costs, and it has a significant effect on the total levelized cost. *Subprogram Manager: Thomas Morasky*

COAL CLEANING

The Coal Cleaning Test Facility (CCTF), located near Homer City, Pennsylvania, is completing its second full year of operation. The facility was designed and constructed by Roberts & Schaefer Co. (RP1400-5) and is operated by Raymond Kaiser Engineers (RP1400-6). Test planning and data analysis are provided by Science Applications, Inc. (RP1400-11) and Kaiser.

CCTF is rapidly achieving industry status as a focal point for coal-cleaning technology development and demonstration. The following efforts have been successfully completed.

- Characterizing coal cleanability, using commercial-scale equipment
- Improving the reliability and accuracy of automatic coal samplers
- Calibrating and verifying the performance of instrumentation required for improved cleaning-plant control
- Developing test plans and procedures

Currently, a series of coal cleanability characterizations are being performed on coals donated by EPRI member utilities and others. These tests are designed to satisfy EPRI R&D objectives, as defined in a comprehensive 1983 test plan, and to satisfy the near-term objectives of utility test coal suppliers.

Test plan and projects

A detailed 1983 test plan was reviewed by the CCTF Technical Advisory Committee, which consists of members of the coal industry and other organizations outside EPRI with interest in coal-cleaning R&D. The 1983 test plan was approved by EPRI's CCTF advisory committee and has been successfully implemented.

The characterization of coal cleanability includes as-received coal analysis and ash and pyrite liberation testing, which are done in strict accordance with test plan specifications to allow direct comparisons between different coals. For example, as-received coals are screened at 6, 1½, ¾, and ⅜ inches; 6, 28, 100, and 200 mesh. The same laboratory analyses are performed on each as-received coal and become the baseline for measuring coal-cleaning benefits.

CCTF flowsheets are custom-designed for each coal according to test-coal cleaning characteristics. In general, at least four flowsheet tests are run for each coal to generate data that will improve the ability to predict performance of commercial coal-cleaning plants. In addition, the flowsheets are selected to accomplish the following.

- Address specific design or operating problems of the coal-supplying utility by duplicating existing or proposed conditions
- Produce a clean coal that meets the supplier's specifications

- Produce a high-quality coal and determine differences in combustion-related parameters associated with improved quality
- Produce a very high quality coal by low-gravity separation and/or by crushing the coal to different sizes

Table 2 summarizes eight 1983 CCTF coal cleanability characterization tests. In the first half of 1983, coal cleanability characterizations were completed on one coal from each major U.S. coal region—eastern: Pennsylvania Upper and Lower Freeport seams; midwestern: Illinois No. 6 seam; western: Montana Robinson seam (subbituminous).

A new type of pressure filter developed in Finland, the Larox Model CF, was demonstrated by dewatering refuse during the Montana subbituminous coal cleanability characterization. To date, the only application of this new filter in the United States has been on copper concentrates. The Larox pressure filter is different from other plate-and-frame-type filter presses because it uses belts for positive cake removal; an inflatable diaphragm for cake squeezing; and an air-dry cycle, blowing compressed air through the filter cake. The incentive for testing this filter is the production of lower-moisture fine coal and refuse than is possible with other types of filters.

The Larox filter has been used in Europe on materials ranging from copper concentrate to phosphate refuse; the CCTF demonstration is its first use in coal cleaning. The filter was tested on bituminous coal refuse during July and August 1983, using Kentucky No. 11 seam coal.

In another development/demonstration project, a Magnadisc magnetite recovery system was tested on a blend of Upper and Lower Freeport coals. Magnadisc, manufactured by a Swedish company, ASEA, has been used in several applications to recover iron ore, but none in coal-cleaning plant operations.

Other development/demonstration projects planned involve pilot-scale (1.4-ft^3; 39-L), multistage, froth flotation; high-G centrifuge performance evaluation; belt filter press; and Super Scalper precleaning classifier.

Sampling, weighing, and instrumentation

All coal producers and users must assess the quality and quantity of coal they handle; the CCTF is no exception. Laboratory analyses of coal samples collected while testing coals at CCTF form the basis of the entire research effort. Precise test plant operating conditions must be maintained so that CCTF test results can be related to commercial-scale operations.

CCTF has 54 automatic samplers located at strategic process points. The sampler types are divided into two broad classifications by material type—bulk solids and slurries. Most of the bulk samplers operate reliably and have been demonstrated to be free of significant bias. Slurry sampler performance varies with flow conditions—pressurized or free flowing (gravity). Efforts to correct unacceptable bias in CCTF's 10 pressurized samplers have been deferred because these samplers are less important to the test plant and the problems with them are more difficult to resolve than those associated with the gravity slurry samplers.

Table 2
CCTF 1983 COAL CLEANABILITY CHARACTERIZATION TESTS

Test Period	Coal Seam	Coal Supplier	Major Objectives	Coal Supplier Benefits
January and February	Upper and Lower Freeport (Pennsylvania)	Pennsylvania Electric Co. New York State Electric & Gas Corp.	Characterize coal ash and sulfur liberation potential	Compare coal supplies
March	Illinois No. 6	Union Electric Co.	Characterize cleanability	Investigate fines cleaning to reduce slagging at power plant and, as a result, increase plant capacity
April	Upper and Lower Freeport	Pennsylvania Electric Co. New York State Electric & Gas Corp.	Compare heavy-media-cyclone geometry and performance	Compare performance of cyclone designs
May	Robinson (Montana)	Central Illinois Light Co.	Characterize a western subbituminous coal Investigate potential cleaning-plant clay buildup and refuse dewatering limitations	Investigate cleaning to reduce slagging
July and August	Kentucky No. 11	Tennessee Valley Authority	Characterize coal Test multistage flotation Compare crushed and natural fines	Obtain data for new fines cleaning circuit design and for improving operation of existing flotation circuit
September	Stockton-Lewiston (W. Virginia)	Buckeye Power, Inc.	Characterize coal Compare dewatering equipment Compare flowsheets	Verify proposed flowsheet and compare with alternative flowsheets before final design
October	Anthracite refuse	Pennsylvania Power & Light Co.	Demonstrate Super Scalper precleaning device and liberation studies on anthracite refuse	Compare water-only cyclone and concentrating-table flowsheets Evaluate anthracite recovery from refuse
November	Kentucky No. 11	Tennessee Valley Authority	Compare performance of fly-ash-derived magnetics and commercial (fresh) magnetite	Assist in economic evaluation of using fly-ash-derived magnetics

Initially, the 31 samplers on gravity-flow slurry lines had poor mechanical reliability and were found to have significant bias. Modifications are being designed and tested to correct gravity sampler reliability and reduce bias to an acceptable level. While the sampler problems are being corrected, manual sampling methods are being used. Table 3 summarizes the status of the CCTF's samplers.

CCTF engineers have developed standard bias-testing, sample collection, and data evaluation techniques. All bias tests are evaluated with the aid of a computer program that identifies erroneous data points and generates bias ranges at specified confidence levels. This computer program is available to EPRI member utilities.

An important CCTF feature is the computer system. The system has four 8-loop digital controllers and two multiplexors, which are monitored by a central (host) computer. To support the CCTF's coal-testing activity, the system performs the following.

- Coal-blending and feed-rate control
- Process-pump flow-rate control
- Data logging and trending
- Test plant status presentation
- Equipment-failure and process-deviation alarms

The computer is capable of handling 608 contact input/outputs, 160 analog inputs, and 32 digital control loops.

CCTF has more instrumentation than commercial coal-cleaning plants. Absolute, rather than relative, accuracy is a requirement of many of CCTF's key instruments so that results can be used in engineering evaluations. The facility has 73 instruments measuring such properties as density, weight, flow, level, and pressure.

Extensive work has been done in calibrating and verifying CCTF instrumentation performance. Many instruments required modification before acceptable performance was achieved. The computer was accepted from the construction contractor in March 1983, and by mid 1983, three-fourths of the original complement of instrumentation was debugged, verified, and in regular use.

During verification of sonic flowmeters on fine-coal slurry lines, observed errors were less than 3–5% of full scale while varying flow rate by a factor of 2, up to full scale. Changes in slurry density for streams with 5–15% solids concentrations had little effect on the accuracy of these flowmeters. A sonic flowmeter installed on a heavy-media-cyclone feed line was found to be sensitive to densities from 1.2 to 1.8 specific gravity. Test work shows that sonic flowmeter density sensitivity is linear and that compensation should be possible.

During 1983 and early 1984, the quantity of instrumentation at CCTF will increase by one-third to support two development/demonstration projects—the pilot froth flotation circuit project and the refuse thickener automation project.

Table 3
CCTF SAMPLER STATUS

Sampler Type	Number Installed	Number Tested	Number Unbiased
Bulk solids	16*	12	10
Free-flowing (gravity) slurry	31	8	1
Pressurized slurry	10	3	0
Total	57*	23	11

*Includes multistage samplers.

Laboratory analyses

The Homer City Coal Laboratory (HCCL) is a research-oriented coal laboratory operated by Pennsylvania Electric Co. and New York State Electric & Gas Corp. About 50% of HCCL's capability is dedicated to analyzing CCTF coal samples. CCTF's widely varying coal types have presented some interesting challenges for HCCL. For example, great effort was recently made to develop reliable procedures for washability analyses of subbituminous coals, batch froth flotation testing, and pulverized-coal gravity fractionation.

HCCL subbituminous coal washability procedures place critical emphasis on moisture retention and processing intervals to minimize moisture variations. Samples are maintained as close to actual moisture conditions as possible throughout processing. All size fractions are wet-screened and immediately containerized to avoid premature drying. Float/sink analysis starts immediately after the surface moisture has evaporated, and the analysis is performed as rapidly as possible. Moisture analysis subsamples are taken at each stage of processing to correct final results to a dry basis. Moisture loss is controlled by sample reduction and chemical analysis.

Bench-scale froth flotation tests are designed to optimize flotation performance. HCCL uses an EPRI–Wemco bench-scale froth flotation cell. A constant-volume makeup water system is used with the cell to simulate commercial plant conditions. Generally, two feed sizes are tested to define the effect of particle size on flotation performance.

A flotation test matrix is used to characterize each coal received at CCTF. Matrix results can be compared with CCTF full-scale cell performance to provide correlations between bench-scale testing and commercial-scale operation. Developing such correlations for process design is a major CCTF objective. As the froth flotation data base develops, it will become a valuable tool for utilities and coal companies interested in cleaning coal by this method.

Until recently, the slagging and fouling potential of a coal was predicted from its average properties. However, average coal properties cannot be used accurately because of wide differences in mineral matter composition and particle sizes in a boiler. Combustion Engineering, Inc., has developed a laboratory gravity fractionation technique that takes into account mineral matter liberation during pulverization. Gravity fractionation is the gravity separation of pulverized coal and may be used to quantify liberation and more accurately predict the slagging and fouling potential of the coal ash in utility boilers.

A 2-lb (0.9-kg) sample is pulverized to 70% minus 200 mesh and introduced into a low-gravity organic prewash to remove slimes. The coal is then separated in a series of organic solutions of different specific gravities (1.3, 1.5, 1.7, 1.9, 2.1, 2.5, and 2.9), with the unfloatable material moving to the next higher gravity. After the separations are complete, the eight fractions are dried and analyzed for percent ash, ash constituents, and ash fusibility. The distribution of iron and alkalies is then used to calculate specific slagging and fouling indexes for the coal ash. CCTF plans to evaluate each test coal by this technique in an effort to provide more definitive information on coal combustion characteristics.

CCTF is producing the data base and technology evaluations to satisfy its long-term objectives. Work on coal samplers, belt scales, and instrumentation and laboratory procedures is providing near-term results that are immediately beneficial to EPRI members. In addition, test coal suppliers are gaining valuable information about the coals they are now burning, while they gain direct access to state-of-the-art coal-cleaning technology. *EPRI Project Managers: Clark Harrison and James Hervol*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Vice President

DISTRIBUTION

Estimating HMWPE cable life

A project has recently been completed that was designed to enable utilities to estimate the remaining life of high-molecular-weight polyethylene-insulated distribution cables (RP1357-1). Earlier progress reports were noted in the May 1981 (p. 41) and June 1980 (p. 55) *EPRI Journal.*

RP1357-1 was initiated to determine the effect that water trees have on the life of full-size polyethylene-insulated distribution cables. The contractor (Phelps Dodge Cable & Wire Co.) prepared 15-kV cables and subjected them to accelerated aging in the laboratory; these cables were examined for treeing, and along with a limited number of older, HMWPE-insulated cables (all aluminum conductor) recovered from the field by several participating utilities, they were subjected to electrical breakdown tests. Results from the field- and laboratory-aging tests were statistically evaluated and compared in an attempt to establish guidelines on how to estimate cable life.

Some cables employed on this project were also subjected to detailed chemical and physical testing and analysis by the University of Connecticut, Institute of Materials Science (RP1357-3); the results of that work are reported in the final report (EPRI EL-3011). The specific objectives of this project (RP1357-1) follow.

- Develop correlations between (1) tree size and density and (2) cable life, when the HMWPE-insulated cables are exposed to normal operation electrical stress and environment
- Develop a method of estimating the remaining life of cables in service and the life expectancy of new cables
- Formulate guidelines on methods to increase the life of in-service and new cables
- Perform statistical testing to correlate the project results

It was anticipated that the life prediction methodology would be based on a comparison of streamer-tree growth for field- and laboratory-aged cables by developing an understanding of electrical breakdown strengths for cables having water trees that penetrate the cable walls to varying extents. The field-aged tree density and length, laboratory-aged density and length, and breakdown strengths for each were to be compared in establishing useful life criteria.

Results showed that the full-size HMWPE-insulated cables aged in the laboratory had reduced electrical strength (*EPRI Journal,* May 1981, p. 41, Figure 1). The 7–10-year-old field-recovered cables also had lower ac breakdown strengths than did the new cables prepared for this project. All cables showed low impulse breakdown, high dissipation factor, and the presence of water trees. Average ac breakdown strength as a function of field operating stress for these cables is shown in Figure 1. However, comparison of field- and laboratory-aged cables on the basis of tree growth (density and length) was not possible from the data, and these results did not lend themselves to obtaining life estimates with respect to water-tree growth as a correlatable factor.

A modified approach to estimating life was employed by using data on ac breakdown strength, which is a property parameter that can be correlated after aging. The data were obtained from identical samples that failed after different aging times under otherwise identical aging conditions—10 cables were employed at 6 kV/mm (150 V/mil) and 7 at 3.4 kV/mm (85 V/mil). This provided a linear relationship (percent survival versus time), implying an exponential distribution, which is employed in reliability applications. These results, combined with ac breakdown data from other laboratory- and field-aged cables, were central to the statistical evaluation of the data, and the life prediction conclusions

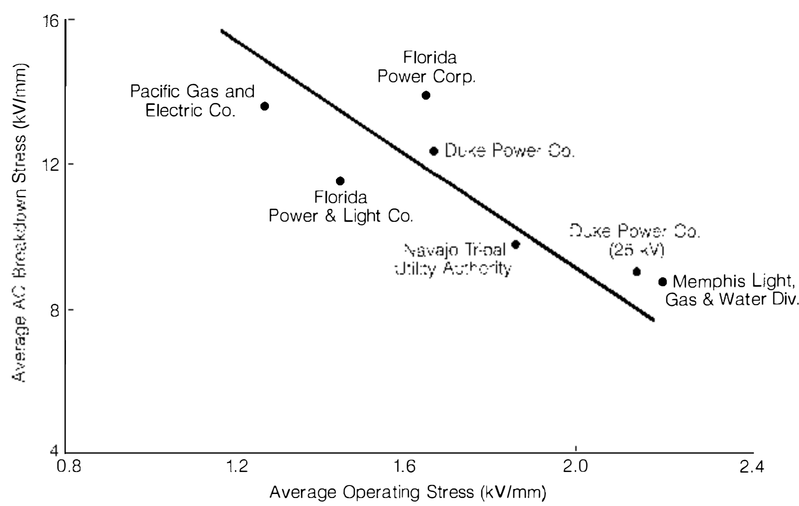
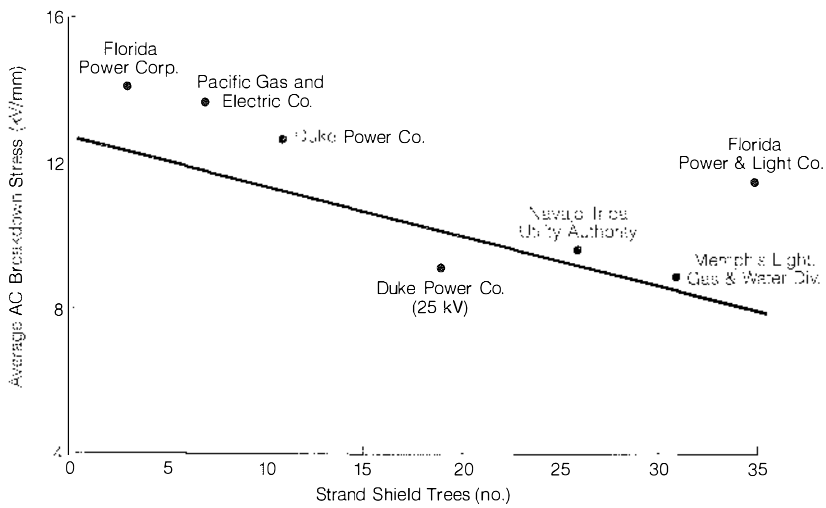


Figure 1 Electrical breakdown strength of full-size extruded dielectric distribution cables as a function of field operating stress (all cables were operated for 7–10 years before being removed and tested). This plot demonstrates that the higher the average field operating stress, the lower the residual ac breakdown strength. (All cables are 15 kV, unless specified otherwise.)

Figure 2 Electrical breakdown strength of laboratory-aged (color data points) and field-aged (black data points) cables as a function of the number of water trees (per unit volume) emanating from the strand shield. As the number of shield trees in the laboratory-aged cable increases, the ac breakdown strength appears to decrease; however, this correlation appears to exist for only some of the field-aged cables, making it difficult to correlate tree counting with either ac breakdown strength or cable life. (All cables are 15 kV, unless specified otherwise.)



were derived therefrom. The following conclusions were drawn from these results.

▫ For laboratory-aged cables, ac breakdown appeared to correlate with impulse breakdown and dissipation factor, but not with bow-tie tree length. A possible correlation exists between ac breakdown and the number of streamer trees (Figure 2).

▫ For field-aged cables, ac breakdown does not correlate with impulse breakdown, dissipation factor, water-tree length or number, or streamer-tree length or number.

▫ Field operating stress appears to be the single most important factor influencing life. The ratio of the ac breakdown strength to the operating stress appears to offer some guidance on remaining life; it is suggested that if the ratio is less than 4, the operating stress has caused sufficient loss of life so that the cable will probably experience an unacceptable failure rate of five or more per 100 mi/yr (160 km/yr).

It was also concluded that the rate of deterioration (i.e., loss of electrical integrity) for the older, warehouse-stored cables was greater than for the cables produced for this project, indicating an aging role for either (1) cable manufacturing aspects or (2) storage after preparation.

It should be emphasized that the conclusions from this project are for HMWPE-insulated cables; there is no certainty that XLPE or ethylene-propylene-insulated rubber cables would behave exactly the same way. *Project Manager: Bruce Bernstein*

Effects of dc tests on extruded dielectric distribution cables

Dc testing of installed dielectric distribution cables has been employed for many years to determine the condition of a cable (i.e., its integrity) or to test a new component added to the circuit (e.g., new section of cable or a splice); it is also used to locate a failure in a direct-buried cable. The first two categories are generally classed as high-voltage proof-testing procedures (with the arbitrary categories relating to cable integrity and cable maintenance); the third is called a fault-locating procedure.

Dc testing is particularly effective for these purposes because extruded dielectric cables have inherently higher dc breakdown strengths compared with ac and low leakage currents. However, in recent years questions have arisen about possible deleterious effects resulting from such testing and whether industry-recommended dc field test values may be too high for aged (e.g., treed) extruded dielectric cables or whether use of dc may impart a latent problem. Considering the age, electrical operating stress, degree of deterioration, and possible influence of the test itself on the cable, a utility may wish to reduce the dc test values or even discontinue dc testing. However, at present not enough information is available on which to base a decision.

Routine proof-testing of extruded dielectric cables is a common practice for some utilities (a continuation of practices applied to paper-insulated lead cables), particularly on main line feeders. In recent years, multiple breakdowns after an initial ac field failure have been reported. Incipient faults could be caused by the high stress resulting from a termination flashover or by a dc failure during fault location. A question exists whether these problems would be present at a lower dc test value. Only recently has it been recognized that cables having undergone deleterious changes during aging might be more susceptible to failure from this type of stress or that incipient changes might be induced as a result of the test itself.

Cables that have been damaged in shipment or by the utility during installation would not necessarily be expected to survive a dc test when it is performed prior to energization—nor would cables that possess substantial imperfections caused during their manufacture. In essence, the dc test would prevent failure from occurring in those types of installed cables when they are put into service.

Dc testing has been used when a new component has been added to the circuit, and it is desirable to verify that it has been properly installed and no physical abuse has occurred. When making such a test, however, the circuit usually includes the older, field-aged cable. If an optimal test stress range exists and is known for the aged cables, the utility would have the option of isolating (to the degree possible) field-aged cables in the circuit so as to minimize the possibility of inadvertently failing these cables.

Fault location testing usually involves a capacitance discharge locator (called a thumper) and is used to precisely locate the failure point in direct-buried cables. If, however, it is determined that the thumper or certain voltage values of the thumper could lead to damage of the cable in the circuit, utilities may wish to employ different types of fault locators or to simply minimize exposure to the thumper.

Published evidence that problems result as a direct consequence of dc testing has not been conclusive. Of course, if a cable fails immediately after proof-testing, the dc test might be considered a success because the deteriorated cable has been located by the test. But if a latent problem is induced as a result of the test and if the cable fails at a later time, it is extremely difficult (if not impossible) to directly relate the failure to the earlier proof-testing. Hence, the possibility of dc testing being harmful, as deduced from field data, is partially based on experience and intuition.

In principle, dc testing of an extruded dielectric cable can lead to trapped space charge that might induce insulation deterioration in an energized system. In practice, whether and to what extent such a phenomenon truly occurs would appear to depend on many parameters. Further, as R&D results over the past five years have shown, different extruded dielectric cables appear to age differently, leading to different electrical lifetimes; hence, isolating the effect of dc testing alone on aged cables is quite complicated. Clarification of the effect on new cables might appear less difficult but would require a full understanding of cable history.

As seen from the above, the influence of dc testing on cables, particularly aged cables, is complex and far from understood. To resolve these questions, EPRI has initiated a three-year project with Detroit Edison Co.—with Essex Wire and Cable Co., a United Technologies Corp. subsidiary, as subcontractor—to determine the effect that dc testing has on field-aged and laboratory-aged extruded dielectric distribution cables (RP2436). The purpose of this project is to definitively determine whether dc testing is harmful to aged distribution cables. When the project is completed, an understanding will have been developed as to what dc test levels, if any, can be employed for proof-testing (or fault locating) of extruded dielectric cables. *Project Manager: Bruce Bernstein*

UNDERGROUND TRANSMISSION

Waltz Mill Underground Cable Test Facility

The Waltz Mill test facility can best be described as a field proving ground for new underground transmission systems (RP7801). Its broad objective is to prove reliability, life expectancy, and suitability of underground transmission systems for utility use. A simplified logic diagram of how the facility meshes with the Underground Transmission Program and how the results make their way to the end user is shown in Figure 3.

Contractors make every effort to design new underground transmission system prototypes with adequate end-user requirements (e.g., no inherent reliability problems). Nevertheless, some system deficiencies do occasionally occur because short-term contractor laboratory testing does not always weed out all problems. The Waltz Mill facility provides the longer-term testing in a field environment (albeit expensive and time consuming) that is necessary to meet user requirements.

A recent example from Waltz Mill illustrates the value of long-term field testing before utility use. The objective of the project was to produce high-quality, high-reliability XLPE-insulated cable systems rated 138–345 kV with insulation thicknesses and operating stresses akin to paper-oil systems (RP7829). The first prototype system rated 138 kV had passed reasonable contractor laboratory qualification tests and was delivered to Waltz Mill for installation and test in 1980. A test program to accelerate aging and simulate cable system life was designed, and the prototype system was put on test in 1981. In August 1982, after 70 weeks of testing, a termination failure occurred.

The failure occurred in the center of an eroded area in a semiconducting boot, which is part of the molded stress control cone assembly (Figure 4). A similar eroded area was found about 150° around the cone from the failure. Although laboratory examination of these eroded areas showed they were caused by electric discharges, various laboratory measurements—shield resistivity, in-

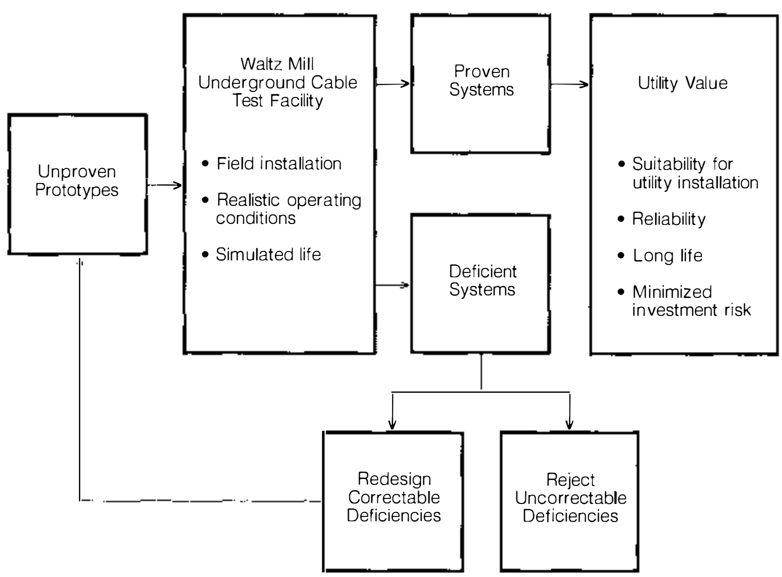


Figure 3 Simplified logic diagram showing how the Waltz Mill Underground Cable Test Facility meshes with the Underground Transmission Program's objectives, ultimately benefiting the end user.

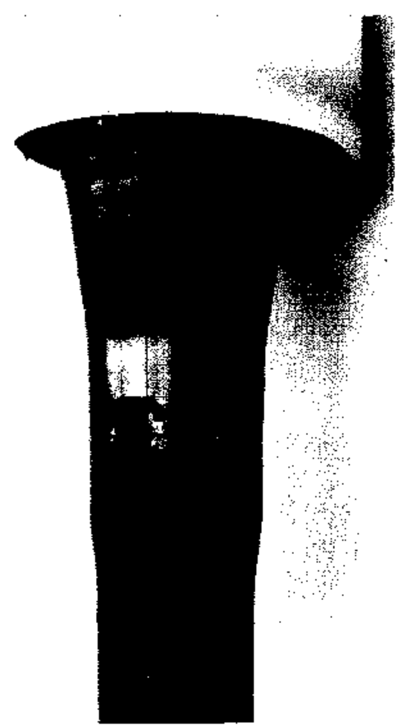


Figure 4 Failure in a 138-kV XLPE cable stress cone caused by electric surface discharge.

sulation breakdown stress, shield adhesion, and so on—showed the cable to be up to standards. However, microscopic examination of the failure channel indicated that the breakdown started from outside the insulation wall and propagated toward the conductor. The cause of failure was therefore external and hence was related to the semiconducting surface erosion that was found.

To allow for thermal expansion of the terminator filling oil, semiconducting ring-shaped sponges were mounted in the bottom of the terminators. These sponges were held in place by six equally spaced rods located so that their ends were about one inch from the stress control cone surface (Figure 5). Inadvertently, these rods were supplied in brass when they should have been nonmetallic. The evidence was clear; under thermal expansion, the stress control cone moved close enough to these metallic rods to cause surface discharges from the cone surface to the rod tip. Calculation showed such discharges to be possible under switching conditions, an operation performed hundreds of times for measurement purposes at Waltz Mill but much less frequently on a utility system.

The solution to the problem in this instance was simple: replace the metallic rods with rods of nonmetallic material. The problem was discovered, analyzed, and rectified before the system could be installed on a utility system. The prototype 138-kV system was replaced at Waltz Mill with both terminations modified, and its test program will be resumed shortly.

Not all the prototypes tested at the Waltz Mill facility that encountered problems were as readily correctable as the example cited. Indeed, the facility testing of state-of-the-art 138-kV extruded dielectric cable systems a decade ago revealed serious problems in manufacturing, quality control, and testing capabilities that took years to overcome. Some problems have yet to be overcome, such as the inadequacy of shield/jacket constructions under high-temperature conditions.

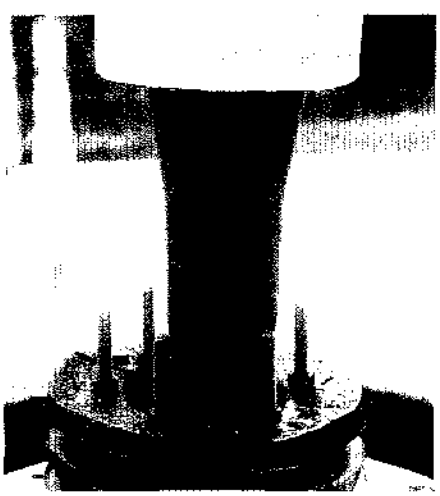


Figure 5 Rods used to keep foam-type material in place at base of termination; rods should not have been made of metal and hence caused failure of the stress cone.

The message appears clear. On the premise that the underground transmission systems are made with high investments, under difficult installation conditions, and at high repair cost, new systems must exhibit high reliability, usability, long life, and user acceptance and confidence. These demands can only be met by long-term testing in a field environment such as the Waltz Mill Underground Cable Test Facility. *Project Manager: John Shimshock*

Losses in pipe-type cables

The accurate calculation of losses in pipe-type cables is necessary for the most economic design and loading of these systems.

As previously reported (*EPRI Journal*, March 1982), the third and final project on this topic (RP7832-3), with Cable Technology Laboratories, sought to develop analytic techniques based on electromagnetic fundamentals that would permit accurate calculation of ac/dc resistance ratios with a minimum of empirical factors. This work is now complete, and a final report will be published shortly. In addition to the final report, where the detailed mathematical derivations are presented, a user's guide will be published. The guide will provide a step-by-step procedure for calculating the ac/dc resistance ratios of three-phase and *n*-phase systems in carbon steel pipes.

Other than the electrical characteristics of the conductor metals (aluminum and copper), the only empirical factors derived from measurements are the conductivity and average permeability of carbon steel pipe and those factors that account for the effect caused by the segmenting of conductors. This latter effect is not readily calculable and is more easily obtained by measurements, as explained in the guide. Recommended values for these empirical factors are given. *Project Manager: Felipe G. Garcia*

OVERHEAD TRANSMISSION

Galloping conductors

Galloping of overhead transmission line conductors continues to be a serious and aggravating problem for the electric power industry. It is viewed as such by utility management because it not only results in power outages during periods of inclement weather but also contributes to human discomfort and/or health hazards. It is also costly, of course, but cost considerations are usually secondary to customer considerations. Fortunately, galloping does not occur very frequently in any one place.

In an attempt to develop a positive solution to this problem, EPRI has been conducting field tests of the detuning-type antigalloping device (Figure 6) on operating utility lines over the past five winters (RP1095). The plan was to attach the detuners to one or two phases of a three-phase line and leave the remaining conductors uncontrolled; trained observers then could report on and compare the relative motions occurring on controlled and uncontrolled phases.

Because galloping is a random event, it soon became apparent that data would accumulate slowly. In addition, each observation appeared to be unique because of the wide variety of storm conditions and the wide variety of line construction methods used at the test locations. Early attempts at interpreting the developing scatter of disjointed data were not very productive.

The project technical team made a concerted effort to develop a normalizing factor that could be applied to all galloping observations so they would yield comparable data. These efforts were successful and resulted in a novel analytic technique that is both workable and defensible.

The major breakthrough occurred as a result of further analysis of industry data developed by EEI's Transmission and Distribution Committee. This data bank was originally used in the preparation of the *Transmission Line Reference Book: Wind-Induced Conductor Motion* (EPRI EL-100-4). Further massaging of these data produced a technique for predicting the maximum theoretical gal-

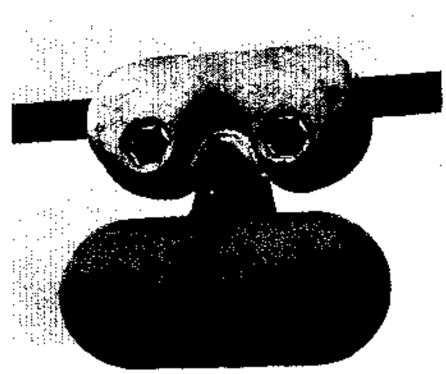
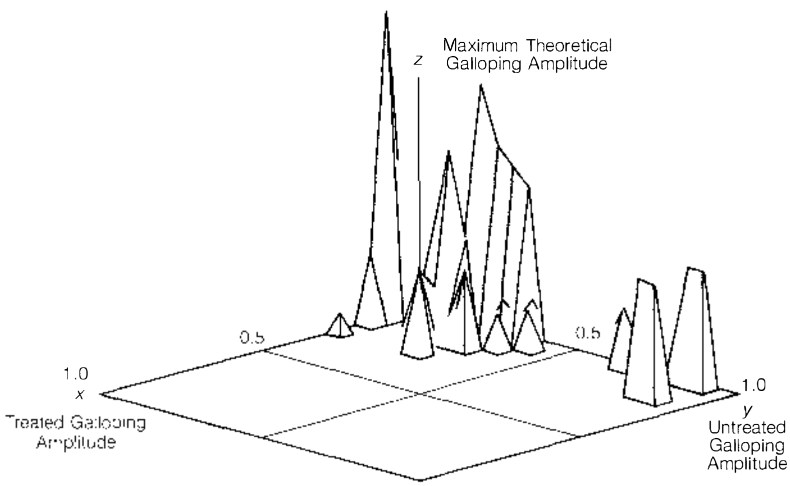


Figure 6 An antigalloping device of the detuning type that offers a positive solution to line galloping. EPRI has been testing this device over the past five winters.

Figure 7 This graph of the ratio of treated and untreated galloping amplitudes to the maximum possible galloping amplitude shows the effectiveness of the treated spans; the lack of plots along the *x* axis shows that the treated spans were almost completely controlled, while both the height (number of instances) and distance from zero along the *y* axis (intensity of galloping) were greater for the untreated spans.



loping amplitude that could occur on any single conductor in terms of its tension-to-unit weight ratio and a certain defined catenary factor. The catenary factor generally takes into account all those parameters that influence the longitudinal flexibility of the conductor system, such as insulator style, sag, flexibility of structure, and foundation. The maximum galloping amplitude provides a useful means for normalizing the reported test results, thus permitting comparison of observed and expected amplitude for both treated and untreated phases.

Figure 7 shows the recently developed technique for displaying results of these comparisons. It provides a good visual picture of detuning pendulum effectiveness by using a three-dimensional locus of the plotted number of observations (z) against the galloping amplitudes of treated (x) and untreated (y) conductors. A few observations may aid in the interpretation.

If the devices controlled the lines perfectly, all data would plot along the y axis. If the devices caused galloping, all data would plot along the x axis; the distance from zero along the x or y axis is a measure of the galloping intensity. It should be obvious that the more tightly packed the data are along the y axis, the better the device is performing.

The data contained in the figure are for all observations of single conductors with diameters 25 mm (1 in) or larger, in span lengths of 100–400 m (274–1097 ft). On the basis of these results, detuning pendulums have been declared a positive control within this range of application conditions. Table 1 is an estimate of the percentage of single conductor lines, by voltage classification, that are within the above range of applications. This suggests we now have the problem reasonably well in hand for lines rated 115–230 kV.

The new analytic techniques also provide a means to glean maximum benefit from data, however sparse. Although little can be done to increase the rate of data accumulation because of natural forces, much more can be learned from whatever data are obtained. For example, milestones should be reached at shorter intervals and on more or less of a continuous basis over the foreseeable future. These milestones are expected to be extensions to the limits of application conditions for single conductors, as well as the performance of pendulums on bundled conductors.

Table 1
GALLOPING DETUNER APPLICATION RANGE

	1982 Circuit Miles	Percent Within Window
69 kV	200,000	25
115/161 kV	176,000	75
230 kV	62,000	90
345 kV	39,000	[illegible]

It appears, however, that detuning is not a universal control. For this reason, the scope of the project was recently expanded to include four other promising devices that mitigate galloping: an interphase spacer, an air flow spoiler, the Windamper, and the T-2 conductor, all of which are commercially available.

The early results are beginning to come in on these alternative systems, which will be recorded and analyzed on the same basis and with the same techniques applied to the detuning observations.

EPRI has extended the testing effort for two more seasons in the hope of bringing this project to a successful close. *Project Manager: Phillip Landers*

Wind-induced conductor vibration

Aeolian vibrations can cause fatigue failure of transmission-line conductors. Utility companies then must often decide whether to replace sections of minimally damaged conductors (from one to four strand breaks) or to add vibration-reducing dampers in an attempt to extend the life of the line.

Phase 1 of this project (RP1278-1) was a preliminary analytic and experimental assessment of the effectiveness of adding dampers to such lines. The results of this work are contained in the final report (EPRI EL-1946).

Phase 2 was an extension of this work to provide the utility industry with guidelines for several representative conductor sizes. The primary objective of this phase was to experimentally evaluate the long-term effectiveness of vibration amplitude reductions in arresting the aeolian fatigue deterioration of minimally damaged overhead conductors. A secondary objective was to develop guideline load–n curves (dynamic bending stress versus number of cycles of vibration), which can be used in the aeolian fatigue design of overhead transmission lines.

Three representative overhead conductor sizes were evaluated. The results showed that the addition of vibration dampers is effective in mitigating line fatigue damage. Guidelines were established to determine the degree of vibration amplitude reduction required to enable a minimally damaged transmission line to achieve its full design life. Load–n curves were developed to aid in rational aeolian fatigue design of overhead lines and for estimating line fatigue life. Work is continuing in Phase 3 to determine the effect of conductor clamp geometry and to develop a better theoretical understanding of this phenomenon. *Project Manager: Joseph W. Porter*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Vice President

BIOLOGIC EFFECTS OF PLUME FLY ASH

Coal-fired power plants produce by-products of combustion that are emitted to the atmosphere. Considerable attention has been paid to some emissions, such as sulfur oxides and total suspended particles, and a substantial amount of research has been carried out on these emissions. In comparison, much less is known about fine particles and adsorbed chemicals that are also in the emissions. It has been hypothesized that fine particles and adsorbed chemicals could affect human health if they occur in sufficient concentration and if they are found to be sufficiently toxic. Currently, the data are too fragmentary to demonstrate whether a problem exists and, if it does exist, how serious it may be. The purpose of this project (RP2482) is to fill the information gap so utilities may design their facilities with confidence that they will meet environmental protection requirements.

Emissions of total suspended particles and sulfur oxides from coal-fired power plants have been greatly reduced through the use of control devices, clean fuel, and adjustments in combustion conditions. Despite these measures, however, power plants still emit some of the fine particles along with organic and inorganic substances.

Chemical and toxicologic data are extremely limited for the emitted particles; hence, any evaluation as to whether human health is affected by such materials is not possible. Limited epidemiologic evidence from the 1950s and 1960s, however, suggests some effect at very heavy ambient particle levels. It is not clear that these early findings are relevant to current ambient particle composition or loading in the United States.

It is commonly assumed that stack-collected samples are suitable for assessing the health effects of particles to which the public is exposed. Numerous studies have shown that in-plant fly ash is generally biologically inert. The limited data on fly ash from the upper reaches of the stack and from the plume suggest that emitted vapors may concentrate as a thin coating on the surface of the particles. This surface coating is expected to increase the biologic activity of the ash, thus bringing into question the assumption that stack-collected samples are a suitable surrogate for assessing impacts on public health.

Fine particles may remain suspended in the atmosphere for long periods and undergo further changes. Such particles may be inhaled by humans and may deposit in the parts of the lung from which particle removal may be slow. It has been hypothesized that the adsorbed material may affect adjoining tissue or dissolve and affect some distant part of the body. This hypothesis needs testing to ensure that current generating-plant design and standards meet the health goals of the society. In addition, information on ambient concentrations will be needed.

Current regulations on particles (e.g., the Clean Air Act, Sections 108/109) are based, in part, on the experience during several air pollution episodes with extremely high levels of atmospheric particles and sulfur oxides. The data include severe episodes in London (e.g., December 1952) and less-intense ones in New York City (November 1963). Recent analyses of these epidemiologic data suggest that the effect during these episodes was due primarily to particles and not to sulfur dioxide.

Currently, regulations consider only total suspended particulate matter, which may not be a relevant criterion to protect human health. It seems likely that future regulations will be based on different parameters, which may include revised regulations based on fine particles (e.g., 10 μm, or less, in equivalent aerodynamic diameter) and regulations on certain chemicals in these emissions.

A meaningful evaluation of the effects on health of utility-derived fine particles can be made only through the conduct of precisely targeted research. In 1982 EPRI initiated a planning study (RP1598) conducted by Gordon A. Enk & Associates. The approach involved three questionnaires, eight critical literature reviews, and four workshops that encouraged scientists to interact and develop a consensus. The study was divided into four parts: short-term toxicology, chronic animal studies, collection and characterization of fly ash, and synthesis. Over 180 biologists, atmospheric scientists, and chemists participated—representing diverse types of organizations in the United States (industry, universities, consulting firms, national laboratories, EPRI, and the electric utilities), as well as several foreign countries. (A summary document on the results of RP1598-1 will be available as an EPRI report.)

EPRI staff have taken the information gathered during the contractor's study, synthesized it with additional perspectives, and developed a plan for a major research project. (Details of the project logic and research plan will also be available as an EPRI report.) Following are the overall objectives of the planned research.

- Assess health effects of fine particles that are emitted from coal-fired power plants and to which people are exposed.

- Assess the feasibility and need of follow-on research on fine-particle emissions and their effect on human health by developing techniques to collect large samples representing ambient conditions; by describing the biologic and chemical/physical differences between samples collected from a coal-fired power plant in-stack and at locations in the plume; and by conducting preliminary toxicity evaluations.

The rationale for the research project includes the following.

- Data on health effects of atmospheric particles are fragmentary and of uncertain quality.

□ Increased use of coal will lead to increased emissions of material that may affect human health.

□ Anticipatory research is far more effective than research done in reaction to pressures because it can provide thorough and timely answers.

□ Data developed during this project can be transferred across disciplines and will be available to facilitate progress in other research topics both within and outside of EPRI.

Conceptually, the project is divided into eight phases. Phase 1 was planning; this began in 1980 and has been completed. Phase 2 focuses on means of storing samples of fly ash from the plume and on means of preserving their characteristics between collection and analyses. It includes collection, biologic analyses, and the chemical/physical analyses necessary for evaluating storage. This phase will build an experimental foundation for the project and ensure the relevance and consistent quality of samples. (Phase 2—RP2482, Task 1—was offered by RFP in November 1983 and will continue for one year.)

Phases 3 through 6 of RP2482 will focus on emissions from one power plant, with examination of many small samples collected under various conditions. The emissions from the selected plant will be collected to (1) describe the changing biologic and chemical/physical characteristics of fly ash from control device to touchdown, (2) describe the variability in particle emissions, and (3) provide reference material of consistent composition and identical origin. Other tasks will include identifying the optimal location for the collection devices, optimization and regular use of techniques for biologic and chemical/physical analyses, initiation of developmental work where necessary, evaluation of laboratory simulators and dilution/aging devices, identification of additional power plants that could be productively studied, data handling, project monitoring and assessment of need, and feasibility of follow-on studies. Phase work is scheduled to begin in 1985 and last for three years.

Phases 7 and 8 will entail major tasks, to be done only if their feasibility and advisability are demonstrated in Phases 3 through 6. The first would be to examine variations among emissions from a number of power plants. The second would be to conduct a long-term animal study, using a fly ash from the first task. Phases 7 and 8 would last for four years. *Project Manager: Blakeman S. Smith*

LONG-TERM SHORTAGE COST ANALYSIS

In recent years the electric utility industry has faced challenges from financing capital investment programs for expanding capacity, siting issues, and various environmental regulations. Higher oil prices in particular and energy prices in general have led consumers to be increasingly concerned about their rising bills. The industry is responding by developing a multifaceted strategy to not only reduce capital requirements and exposure to risk but also provide low-cost and reliable service. EPRI's Energy Analysis and Environment Division is developing analytic tools that will help utilities minimize total capital requirements, as well as allocate scarce resources more efficiently across power generation, transmission, and distribution. One area of research (RP1988) is directed toward assessing long-term shortage costs. This factor is an important value in capacity expansion decisions. A utility attempts to minimize capital investment and simultaneously ensure a reliable supply of electricity—from the customer's perspective—that is neither more than adequate (thereby resulting in customer bills that are higher than necessary), nor less than adequate (thereby resulting in low electric bills but increasing the chances of too many supply interruptions). To be able to properly determine the optimal plan, the utility planner must know the value of reliability to the customer or, conversely, the cost of shortages.

When making a decision to increase capacity during the 1950s and 1960s, a least-cost capacity plan was identified that was to satisfy the forecasted demand and provide adequate reliability. That approach often did not include the feedback between the electricity price required to provide service at the chosen reliability level and the level of demand. In addition, the definition of *adequate reliability* was based on cumulative historical experience and engineering criteria. The outcome was the creation of a highly reliable power supply system. Because the cost of generating stations and fuel was decreasing, these decisions also resulted in an almost continuous decline in the price of electricity.

Following the rapid increases in electricity prices during the 1970s, many utility executives and regulators question rule-of-thumb approaches. They feel that investments in electricity supply should be based on a careful evaluation of the costs and benefits of alternative investment levels and that explicit consideration should be given to all classes of costs—capital, operating, shortage, and environmental. An economic cost-benefit approach has been used in the planning process for several years in other countries, such as Norway, Sweden, Finland, and Italy. Recently, Ontario Hydro switched to this approach, and the Electricity Division, under the Ministry of Energy in New Zealand, is evaluating the possibility of adopting it. However, in all these studies, such factors as health, increased reliance on foreign energy supplies, and so on were not included in the analysis.

The major hurdle in implementing a cost-benefit analysis for electricity supply planning stems from the lack of objective, credible, and defensible estimates of the impact of alternative levels of reliability on the customer. Whereas the literature on the economic costs of electricity interruption in Europe dates back to the early 1960s, systematic and precise attempts at developing theoretically correct methods are limited and have been made only recently. An early research project (RP1374) concluded that estimates of electricity interruption (outage) costs vary widely by customer class, as well as being a function of such key outage descriptors as time of occurrence, duration, shortage management strategy (warning time), and frequency.

Table 1 summarizes the order-of-magnitude of the range of outage cost estimates for energy and capacity-related outages that are typically found in the literature on this subject. Recent EPRI workshops have reviewed the state of the art of estimating the costs of short-term capacity shortfalls (EPRI EA-1104).

In the table, a capacity shortfall refers to a situation wherein the amount of capacity is insufficient in relation to peak demand. Capacity-related outages typically stem from the irreducible element of uncertainty that

Table 1
ESTIMATES OF OUTAGE COSTS
($/kWh)

	Energy	Capacity*
Residential	0–0.50	0.05–1.50
Industrial	0.05–1.00	1.00–7.00
Commercial	—	1.00–10.00
All sectors	0–0.50	1.50–3.00

*Stated in cost per kWh, although conceptually the shortage is one of kW over time.

characterizes any power system—the potential for load to exceed available system capacity irrespective of the reserve margin or the amount of planned transmission and distribution reliability. Capacity-related interruptions are often of short duration and there is little or no warning. Although frequently thought of as arising at times of daily and seasonal peak loads, they can happen in any season of the year on most systems.

An energy shortfall, on the other hand, refers to a situation wherein the average amount of electricity (in kWh) that would be purchased over a specified time period exceeds the energy availability over that same period. An energy shortfall is usually the result of insufficient fuel. Such shortfalls are generally of extended duration—from weeks to months—and are preceded by a warning.

Shortage costs

In general, customers have certain expectations about the reliability of future electricity service. Expectations arise from past experience with interruptions in supply or other measures of degradation in the quality of service. Based on these expectations, some classes of customers may consider mitigating options that can reduce potential outage costs. These reductions in future outage costs will, therefore, come at the expense of incurring certain costs at the present time.

For example, long-term mitigating measures include installation of voltage regulators, protective switchgear, load management, conservation, cogeneration, standby or self-generation, permanently switching to alternative fuels (or simply installing the capability), or carrying larger in-process inventories. If implemented, each of these options for reducing future outage costs has associated fixed and variable costs. Such costs are adaptive response costs, or long-run coping costs. Shortage costs refer to the sum of expected outage costs and adaptive response costs.

The major objective of a current project (RP1988) is to develop a set of methodological tools for estimating shortage costs by customer class or, equivalently, the value of electric service reliability to each class. The correct measure of this value is the consumer's willingness to pay for the associated level of service reliability. The approaches to estimating values for the willingness to pay range from questionnaires to statistical analysis. In this project, each method is evaluated for theoretical validity, robustness, and other criteria, developing the pros and cons of several alternative estimation approaches for testing the methods on two case studies. The complexity of the issues involved requires several approaches to help define the range of uncertainty affecting each estimate. The case studies will be particularly useful in assessing the uncertainty and its sources.

Decision-making framework

The objective of this portion of the study is to develop a decision-making framework for using the information on shortage costs to arrive at optimal investment decisions. The emphasis is on integrating shortage costs into utility resource planning models. Potential applications within generation, transmission, and distribution planning are being considered, and where necessary, different decision-making frameworks will be developed.

A case study will be conducted to implement some of the methods developed, using data from a participating utility.

A systematic step-by-step approach for estimating shortage costs and their use in utility investment planning and decision making will be presented in a workshop, and the computer software developed expressly for this project will be documented. *Project Manager: Paolo F. Ricci*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Vice President

COMPRESSED-AIR ENERGY STORAGE

*A 290-MW (50-Hz) compressed-air energy storage (CAES) plant has been successfully operating for load leveling in Huntorf, West Germany, since 1978. Improved versions of this energy storage technology are being considered for installation as intermediate and peaking contributors to utility generation systems in the United States. Such plants can be built in module sizes of approximately 220 MW and constructed in 3–4 years, and module sizes in the 20-MW range are on the drawing boards. Since 1979 EPRI has been working with the utility industry to assist in the commercialization of this technology. EPRI's work on CAES has included preparing preliminary engineering designs for first- and second-generation CAES plants (*EPRI Journal*, May 1981), investigating unresolved issues, and developing planning tools. These efforts are aimed at reducing the risks to manageable levels so that utilities can confidently compare CAES with other existing alternatives for meeting intermediate and peaking needs.*

The operation of a CAES plant is similar to that of a pumped-hydro plant: storing off-peak energy for later use when the utility's loads are high (peak and intermediate time periods). However, the CAES storage medium is air instead of water, and the energy storage reservoir is belowground in rock, salt, or aquifer geologic formations, rather than aboveground on hills or mountains. CAES plants are economic in much smaller sizes than pumped hydro and therefore require less capital and construction time. Typically, pumped-hydro plants are economic only in large sizes (~1000 MW), whereas CAES plants are economic in module sizes of ~220 MW and possibly as small as 20 MW.

Of the three formations used for CAES, salt domes as storage reservoirs are the best understood because salt formations are in use at the West German plant and at numerous oil/gas storage depots in the Gulf Coast area. Because aquifers have never been used for daily storage of fluids, they were thought to have a high risk for CAES application. After DOE and EPRI efforts, however, this type of geology is proving to be almost risk-free and is the least expensive and most flexible of the geologic formations. Excavated rock formations used for storing hydrocarbon fuels are also well understood; their use for air is technically feasible but poses a few special, but solvable, problems.

One of the issues studied by EPRI is the geologic potential for siting CAES plants in the United States. Letters were written to each of the state geologic surveys, asking for geologic maps indicating the regions throughout their state that would satisfy the requirements imposed by CAES caverns. A geologic consultant analyzed and assembled this information on a state and national basis, with the result that the geologic opportunities for CAES plants are very broad and cover about three-fourths of the United States (Figure 1). The results of this effort will be included in a simplified evaluation manual being prepared on CAES to assist utilities that are considering CAES as a future option in their generating mix.

Aquifer field test

An issue currently under study is whether an aquifer formation can be used to cycle air on a daily basis. It had been thought that the extrapolation of data from 40 years or more of seasonally cycled natural gas storage aquifers would yield unacceptable uncertainties about the daily cycling of air, a more viscous (by 70%) and oxygen-laden gas. A field test to resolve these uncertainties was

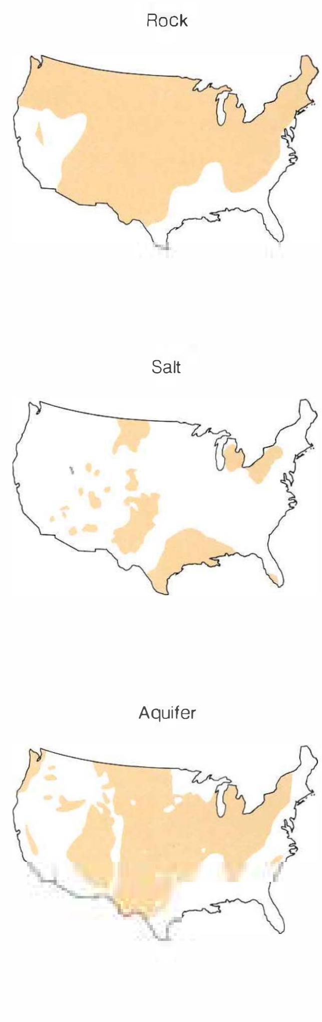


Figure 1 Geologic regions potentially suitable for siting compressed-air energy storage plants. Note that about three-fourths of the United States has siting opportunties for one or more types of CAES plants.

initiated by DOE at a site near Pittsfield, Illinois. Because of budgetary constraints at DOE, EPRI took over the project in February 1983, completing the "bubble" development process and then performing air-cycling experiments at specified temperature levels and time intervals.

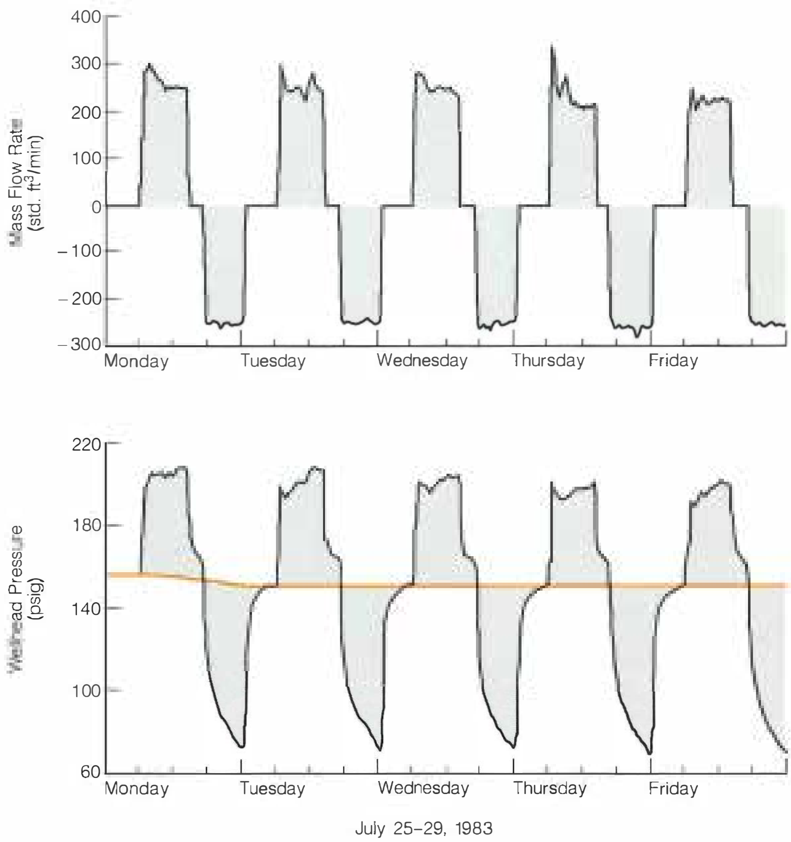
The test facility is located over the apex of the so-called Pittsfield anticline, which is about 47 km (29 mi) long, striking northwest to southeast. The test facility is on the southeast end of the anticline. The aquifer formation is a St. Peter sandstone, starting at a depth of about 198 m (650 ft). Its porosity is 18% and its average permeability is 750 millidarcies. Dolomite rock provides an impervious caprock over the formation and isolates it from irrigation water aquifers, as required for all potential CAES aquifers.

Preliminary results from the field test are very encouraging. To date, a number of accomplishments have been achieved that are a first for the industry.

- Air has been successfully pumped and stored in an aquifer.
- Air has been successfully cycled on a daily basis in an aquifer.
- Equations used for seasonally cycled gas storage aquifer reservoirs have been shown to reasonably predict the performance of a daily cycled air storage aquifer reservoir.

Example results for a specific type of daily cycle experiment at the test facility are given in Figure 2. Results from other test conditions are being acquired, including operating the injection and withdrawal cycles of the aquifer reservoir under (a) constant pressure and letting flow vary; (b) constant flow and letting pressure vary; and (c) air injection at specified temperatures (ambient, 50°C, 125°C, and 200°C) and measuring the withdrawal air temperature transient. The tests are currently scheduled to end in 1984 and the project final report should be available shortly thereafter.

Figure 2 Daily cycling of air into and out of the Pittsfield aquifer during the seventeenth week of cycling (July 25–29, 1983). The color line in the lower graph represents apparent static pressure.



Champagne effect

The use of excavated rock caverns for storing compressed air is also being studied. With this type of storage it is preferable to operate the cavern at constant pressure to reduce the volume and the associated cost of the cavern, rather than at a variable pressure (as in salt or aquifer air storage reservoirs). The constant pressure is achieved by means of a static head of water that connects the underground cavern to a small surface reservoir. This approach reduces the size of the cavern by a factor of 5 (compared with salt reservoirs); however, associated with this design approach is the potential problem arising from air dissolving into the high-pressure cavern water and coming out of solution in the upper portion of the vertical water shaft. It has been postulated that gas formation might be extreme enough to cause unacceptable flow instabilities during the charging process. However, a two-phase-flow computer simulation of the problem shows the damping forces associated with the cavern-piping geometry and air bubble physics will reduce the instability to acceptable levels (EPRI interim report for RP1791-2). To confirm the computer simulation predictions for this phenomenon, a 18-bar (1.8-MPa) field test is being performed to acquire the necessary calibration data. Results of this work are expected to be available in late 1984. *Project Manager: Robert Schainker*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

EXTENDING FUEL BURNUP

Minimal fuel cycle costs are realized at fuel burnups that are considerably higher than those currently obtained. Therefore, utilities are gradually increasing batch average exposures. These increases must be accompanied by a better understanding of fuel performance to ensure reliable performance and acceptance by licensing authorities.

The average discharge burnup of LWR fuel has been generally increasing since the first power reactors began operation. Until the late 1970s there were several phenomena that often limited the burnups of fuel batches to less than the design exposure. Therefore, most of the R&D effort was focused on improving fuel reliability.

During the 1970s primary Zircaloy hydride failures were eliminated by improved manufacturing methods that reduced moisture levels in fuel rods; manufacturing-defect-related failures were reduced by improved manufacturing methods and better quality control; and Zircaloy cracking following power increases (pellet-cladding interaction) was brought under control by decreasing fuel rod power and restricting the rate of increase in power. With the resultant improved performance and attainment of design exposures (~33 GWd/MtU for PWR fuel and ~28 GWd/MtU for BWR fuel), EPRI, DOE, fuel vendors, and utilities began to consider extending fuel burnup to exposures that minimize fuel cycle costs.

These exposures were generally estimated to be about 50% higher than those currently being obtained. Although this increase in exposure is an ambitious goal, all the evidence to date indicates that it is technically achievable and some utilities have successfully obtained higher burnups than 35 GWd/MtU in PWRs.

EPRI and DOE have coordinated their extended-burnup programs to provide data on the technical issues related to reliability and licensing. The primary concerns are Zircaloy water-side corrosion, fission-gas release, Zircaloy cracking following power increases, Zircaloy hydrogen embrittlement, and dimensional stability. In general, EPRI has emphasized obtaining detailed data on highly characterized, high-exposure fuel assemblies of standard design, and initial test reactor studies of advanced fuel types. DOE has emphasized irradiation of advanced fuel designs that are intended to increase reliability to high exposures and the examination of uncharacterized fuel after high exposures. In one project demonstrating advanced fuel designs, the Empire State Electric Energy Research Corp. is cosponsoring irradiation with EPRI. Together, these programs are demonstrating that high fuel exposures can be obtained without sacrificing fuel reliability or increasing risk to the public.

Current design fuel

EPRI has sponsored projects with Westinghouse Electric Corp. (RP611) and Combustion Engineering, Inc. (RP586) to irradiate current design PWR fuel to 55 GWd/MtU exposure. A similar project with General Electric Co. (RP510) is extending the exposure of BWR fuel to approximately 42 GWd/MtU. These highly characterized assemblies are being examined in detail to determine the dimensional stability of fuel rods and assemblies, the corrosion rate of the external surface of the Zircaloy tubes that contain the fuel pellets, the amount of fission gas released from the fuel pellets, and the detailed microstructural changes in the fuel pellets.

PWR fuel has exhibited acceptable behavior. Dimensional measurements show that the fuel rod length changes and bowing and the fuel assembly bow and twist are generally as predicted by design descriptions. Zircaloy oxidation rate at the coolant water interface has not accelerated (typical oxide thicknesses are 30–60 μm). Hydrogen pickup by the Zircaloy is normal (less than 150 ppm) and not enough to excessively embrittle the tubes. Fission-gas release from the fuel pellets has generally been low—on the order of 1% of the gases generated, with a few instances of releases on the order of 10%. Detailed microstructural examinations of the fuel pellets are providing benchmark data for detailed models that predict changes in fuel dimension (densification and swelling), temperature profiles, and fission-gas release.

Over the next two years, examinations of General Electric's fuel for BWRs will provide similar data. The design and operating conditions of BWR fuel dictate an emphasis on Zircaloy corrosion and fission-gas release in these studies.

Advanced designs

EPRI test reactor programs at the Halden Project (RP355) and at Studsvik, Sweden (RP1580), have investigated the performance of three types of fuel pellets: radially zoned, enriched duplex pellets; large-grain, niobia-doped annular pellets; and standard annular pellets. The duplex and the doped-annular pellets have had very good performance characteristics, while the annular fuel has shown mixed results.

Duplex pellets are composed of two parts: an outer ring with highly enriched uranium and an inner annulus of natural or depleted uranium. Because most of the heat is generated in the outer ring, the pellets operate at significantly lower temperatures than standard fuel pellets at the same heat rating. This results in low fission-gas release, little pellet cracking and relocation, and reduced mechanical interaction between the fuel pellets and the Zircaloy cladding. This extends rod life by reducing internal rod pressure and improves reliability by decreasing the driving forces for stress corrosion cracking.

Fuel pellets doped with Nb_2O_5 have large grains and high creep rates. For optimal Nb_2O_5 concentrations, the large grains result in low gas release. With appropriate design, the high creep rates can prevent high cladding stresses and thereby decrease the probability for stress corrosion cracking of the Zircaloy cladding.

EPRI is continuing research on duplex and doped-annular fuels. However, the industry's interest in annular fuel is adequately covered by DOE programs and EPRI will not sponsor additional work.

A joint industry effort, the nuclear fuels industry research project, is supporting fundamental research into Zircaloy corrosion, UO_2-Gd_2O_3 thermal properties, UO_2 microstructural changes, and B_4C irradiation effects. EPRI is managing the program.

EPRI projects will continue to sponsor research in support of extending fuel exposures through this decade. Potential savings are large: on the order of several hundred millions of dollars per year in the 1990s. *EPRI Program Manager: David Franklin*

REACTOR ANALYSIS SUPPORT PACKAGE

The reactor analysis support package (RASP) project, RP1761, was initiated to provide utilities with analytic tools for describing nuclear power plant behavior and performance. With these tools utilities can gain some measure of independence from nuclear steam supply system (NSSS) and fuel vendors, should they wish to do so. The objective of the project is to produce a verified and validated package—computer codes, code documentation, and application guidelines—that can be used by utilities for both fuel reloading and plant safety analysis.

The experience of the last 10 years has demonstrated a growing need for utilities to have the means to perform independent reanalyses of the postulated events that make up the operational design basis of nuclear plants. This need stems primarily from revised NRC requirements for best-estimate (versus bounding) analyses and from new attention to the specifics of various safety concerns. Since the accident at Three Mile Island, two factors in particular have increased the demand for a reanalysis capability: the need for operator guidelines based on realistic predictions of system performance, and the increasing acceptance and use of mechanistic input to probabilistic risk assessment (PRA).

Such operator guidelines and risk assessments require best-estimate predictions of plant performance after postulated disturbances. Previously developed analytic methods, however, especially transient thermal-hydraulic codes, are to some degree inherently conservative and cannot meet these needs. The RASP computer code system has been developed to provide the nuclear utilities with a comprehensive methodology for realistic operating-plant analysis.

PRA is now being emphasized by many

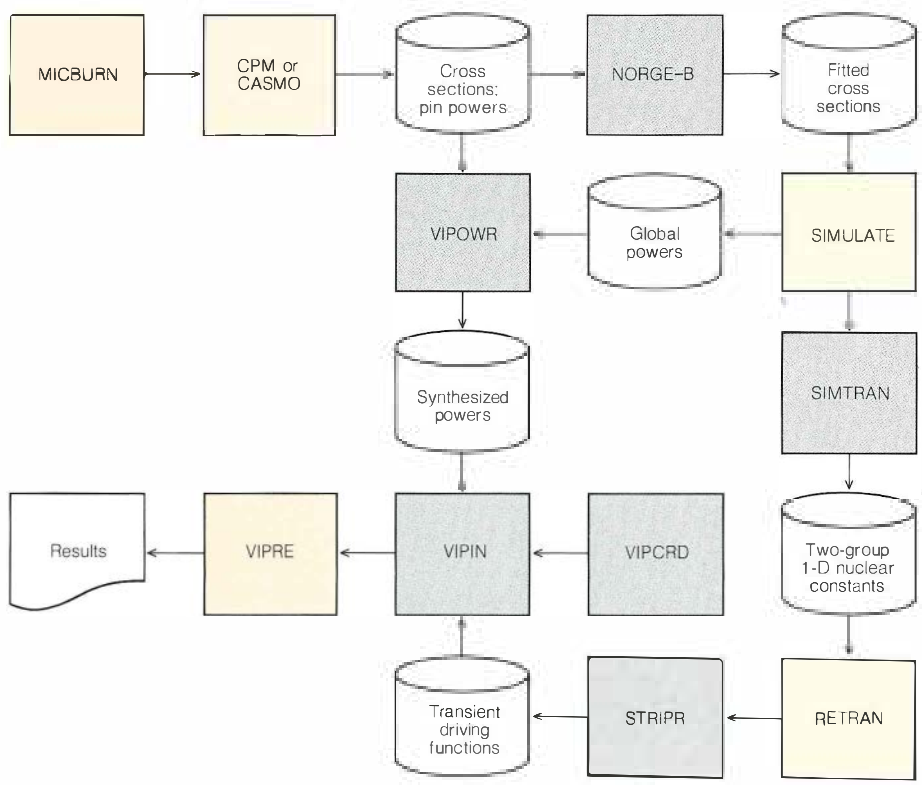


Figure 1 General RASP code sequence for LWR safety-related analyses. This sequence is applicable to BWRs and in some cases to PWRs. The RASP code system includes several linkage codes (gray) that take output from one main code (color) and process it for input to another. The ARMP core physics codes used here are MICBURN, CPM, CASMO, NORGE-B, and SIMULATE.

utilities. The use of this methodology requires best-estimate calculations of many plant occurrences. The RASP code system is capable of providing this input from detailed plant-specific analyses.

RASP capabilities and structure

EPRI has sponsored several individual nuclear analysis code development efforts. The RASP project was undertaken to consolidate the products of those efforts into a comprehensive, consistent code package. It involves the development of special code linkage software, the thorough prerelease testing of the consolidated methodology, and the preparation of application guidelines. When these tasks are completed, the next step is for utilities, supported by EPRI through coordination groups and code users groups, to develop plant-specific models and eventually to apply them to safety-related analysis for regulatory review.

The origins of RASP can be found in EPRI projects to develop the RETRAN reactor system transient analysis code (RP889) and the ARMP core physics analysis methodology (RP118). RASP builds on these best-estimate methodologies, extending the range of application in logical steps that are consistent with utility needs and EPRI software availability. To facilitate use and eliminate potential sources of analytic error, RASP includes automated linkage software as well as fundamental technology codes. The resulting code package can be applied to the following tasks.

- Performing plant-specific safety analysis
- Supporting reload core licensing
- Performing fuel cycle management analysis
- Analyzing anticipated operational events and accidents
- Determining protection system setpoints
- Determining limiting conditions for operation
- Determining the impact of potential design changes
- Providing an analytic basis for changes in technical specifications

Figures 1 and 2 show the two general RASP code sequences developed to date. At the beginning of each sequence is a series of LWR physics analysis codes from the ARMP package. Here the ARMP codes are used to calculate the fuel parameters required in system and core thermal-hydraulic analysis. ARMP can also be used in a stand-alone mode for fuel cycle management analysis. The RETRAN system thermal-hydraulic code can perform complete plant transient analyses for both BWRs and PWRs. Its flexible structure also enables it to be used for the

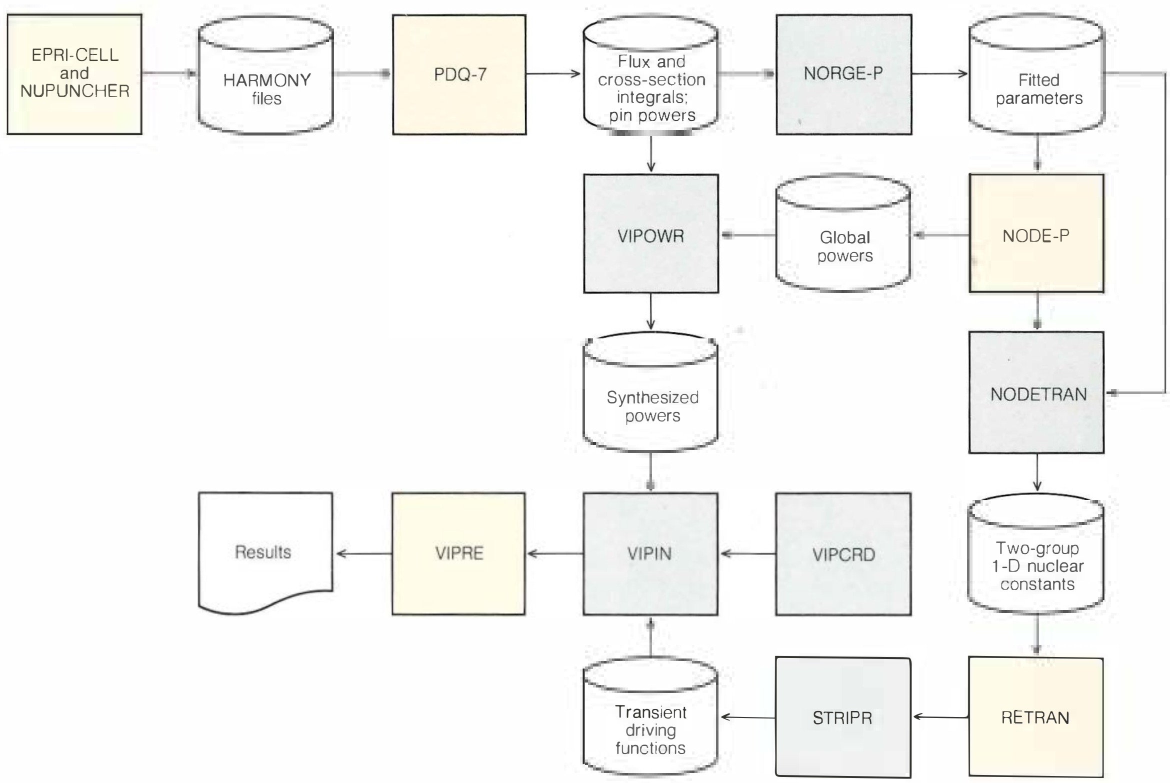


Figure 2 General RASP code sequence for PWR safety-related analyses. The main codes are shown in color, and the linkage codes in gray. The ARMP core physics codes used in this sequence are EPRI-CELL, NUPUNCHER, PDQ-7, NORGE-P, and NODE-P.

analysis of test facilities and separate plant components. RETRAN has been applied to the full spectrum of postulated safety-related plant thermal-hydraulic events. Its nuclear kinetics models, which relate core power response to thermal-hydraulic perturbations, require input from the ARMP code package via special linkage codes. The VIPRE core thermal-hydraulic code, also applicable to both BWRs and PWRs, uses RETRAN-calculated core boundary conditions to determine the detailed core response, including the margin to fuel licensing safety limits. VIPRE requires initial core power distribution parameters from ARMP.

RASP status and documentation

The RASP code system, currently being used by utilities on a prerelease basis, is geared toward economical, everyday use by utility technical staffs. The methodology is, for the most part, state of the art and as good as, or better than, the equivalent methodologies of NSSS and nuclear fuel vendors. The ARMP and RETRAN codes have been extensively validated against data and have been used by several utilities in fuel cycle management and licensing support analyses. The validation process has also been completed for VIPRE, and the code is being formally released for utility application. An automated linkage and data base management system using DATATRAN (*EPRI Journal*, November 1981, p. 14) has been developed that records the calculation history of a RASP job. This allows the engineer to trace the calculation steps at a later time and greatly enhances the quality assurance process.

Adequate documentation is the key to ensuring that the RASP code system serves the needs of the utility user community. A major RASP project activity is to provide the guidance needed for effective use of the code system. It should be noted that a single power plant can be properly modeled in many ways, depending on, among other things, the postulated event to be simulated and the reason for performing the analysis.

Each of the computer codes in RASP is thoroughly documented with respect to theory, program structure, user input and output, and applications. In accordance with the usual EPRI format, these areas are covered in four-volume computer code manuals. Further, for the main RASP codes, EPRI has decided to update the manuals to include a fifth volume on modeling guidelines. Work on such guidelines is already under way for the RETRAN and VIPRE codes.

To supplement the individual code manuals, several other documentation efforts have been initiated. A RASP overview report and a user's manual for the DATATRAN automated linkage system are in draft. Also, guidelines for using RASP are currently being prepared in four application areas: BWR physics analysis, PWR physics analysis, BWR event analysis, and PWR event analysis. The event analysis guideline work will continue through 1984, and guidelines for each event will be made available to utilities as they are completed. RASP guidelines for PWR setpoint analysis are also planned.

To ensure that the RASP development effort stays on target to meet user needs, a utility advisory structure has been established. The utility steering committee for RASP, which is a subcommittee of the Safety and Analysis Task Force of EPRI's Nuclear Power Division, acts in an advisory capacity on plans for RASP growth and enhancement. Under the steering committee are two coordination groups, one for BWRs and one for PWRs, which are made up of utility technical personnel with detailed plant analysis experience. The major responsibility of these groups is to review the RASP analysis guidelines to ensure that the methodology will be applied correctly. The existing utility users groups for ARMP, RETRAN, and VIPRE provide a forum for sharing experience and communicating specific code modification requests to the EPRI project managers and contractors responsible for code development and maintenance.

In conclusion, RASP is the first available automated computer code system that can perform a complete reactor physics and thermal-hydraulic analysis of an NSSS. RASP will provide a verified, validated, and thoroughly documented package that traces the analysis through the entire calculation sequence. This package should be easier to use and more reliable than previous methodologies and is particularly suitable for quality assurance and formal licensing activities. *Project Manager: Lance Agee*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP2111-2	Energy Storage Options for an Integrated GCC Power Plant	1 year	99.8	PGS Hydrogen Products *G. Quentin*
RP2302-1	Molten Salt Electric Experiment	38 months	1150.0	Department of Energy *E. DeMeo*
RP2357-1	Autoignition and Flame Speed Characteristics of Medium Heating *Value Coal Gases*	11 months	196.1	United Technologies Research Center *L. Angello*
Coal Combustion Systems				
RP1031-5	Reaction Mechanism of the Oxidation of the Bisulfite Ion by Oxygen	9 months	40.0	Lawrence Berkeley Laboratory *D. Stewart*
RP1031-6	Synergistic Effects of FGD Impurities on Sulfur IV Oxidation	19 months	120.0	University of California at Berkeley *D. Stewart*
RP1031-9	FGD Chemistry Pilot Tests and Model	22 months	688.5	Radian Corp. *D. Stewart*
RP2428-2	PFBC Turbocharged Boiler: Design and Economic Study; Design and Cost Estimate	14 months	1119.1	Brown Boveri Corp. *S. Drenker*
Electrical Systems				
RP2206-1	Demonstration of Large-Scale Direct Analysis of Power System Stability	31 months	144.6	Ontario Hydro *J. Mitsche*
RP2284-1	Effect of Voltage Surges on Solid Dielectric Cable Life	3 years	615.2	Southern Electric International, Inc. *H. Songster*
RP7897-4	Characterization and Evaluation of Products Generated Through Arcing in SF_6 Gas in the Presence of Dielectric Materials	19 months	180.9	Westinghouse Electric Corp. *B. Bernstein*
RP7897-5	Computerized Data Base on Dielectric Materials	19 months	247.5	Purdue Research Foundation *P. Garcia*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Energy Analysis and Environment				
RP1488-2	Application of Ecological Assessment Model to Lake Norman	9 months	49.7	Tetra Tech, Inc. *J. Mattice*
RP2314-3	Utility Fuel Inventory Models	18 months	132.5	Decision Focus, Inc. *H. Chao* *S. Chapel*
RP2314-4	Utility Fuel Inventory Models	18 months	147.0	Applied Decision Analysis, Inc. *H. Chao* *S. Chapel*
RP2374-1	Health Effects: Assessment of PCBs	15 months	320.0	Clement Associates, Inc. *W. Weyzen*
Energy Management and Utilization				
RP1276-18	Cogeneration System Design and Evaluation: Utility Co-owned Industrial Parks	18 months	487.9	Burns & McDonnell Engineering Co. *D. Hu*
RP1677-9	System Planner's Guide: Evaluation of Phosphoric Acid Fuel Cell Power Plants	6 months	56.8	Burns & McDonnell Engineering Co. *D. Rigney*
RP2219-1	Plasma-Fired Cupola Development	19 months	785.1	Westinghouse Electric Corp. *A. Karp*
Nuclear Power				
RP1750-4	Validation of ENDF/ B–V Data in LWR Analysis	1 year	135.0	Union Carbide Corp. *O. Ozer*
RP2013-1	Oil Acidity Monitor System Development	25 months	251.4	Mechanical Technology, Inc. *J. Matte*
RP2079-5	Dissimilar Metal Weld Design Criteria	11 months	78.4	G.A. Technologies, Inc. *R. Nickell*
RP2352-1	Analytic Capability for Predicting Gamma Detector Response Functions	16 months	238.3	Studsvik Energiteknik Ab *O. Ozer*
RP2399-1	Integral System Test Program: Once-Through Integral System and Multiloop Integral System Test Component	57 months	1200.0	Babcock & Wilcox Co. *J. Sursock*

New Technical Reports

Each issue of the *Journal* includes information on 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 in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of all EPRI reports on request. Microfiche copies are also available from Research Reports Center, at the address given above. The price per volume of $6.00 in the United States, Canada, and Mexico and $12.00 per volume overseas includes first-class postage.

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ADVANCED POWER SYSTEMS

Analysis of Coal Devolatilization in a Laboratory-Scale Entrained-Flow Reactor

AP-2603 Final Report (RP1654-8); $16.00

This report describes a study to develop techniques for predicting the pyrolysis behavior of coal under conditions typical of entrained-bed gasifiers. Measurements of coal pyrolysis were made in a laboratory-scale entrained-flow reactor with the capacity for in situ analysis by Fourier transform infrared spectroscopy. These data were then used to modify and validate a general coal pyrolysis theory. The contractor is Advanced Fuel Research, Inc. *EPRI Project Manager: G. H. Quentin*

Photovoltaic Systems Assessment: An Integrated Perspective

AP-3176-SR Special Report; $14.50

Information from recent photovoltaic (PV) research and technology assessments was synthesized into a review of key planning, hardware, institutional, and operational issues. Researchers reviewed PV cell and module technologies, results from ongoing field tests of intermediate-size systems, and balance-of-system (non-PV components) costs for residential, intermediate, and central station applications. Cost-performance targets for PV systems in various locations were developed. *EPRI Project Manager: R. W. Taylor*

Photovoltaic Field-Test Performance Assessment: Technology Status Report

AP-3244 Interim Report (RP1607-1); $17.50

This report is the second in a series of status reports to describe field-test operating experience with the present generation of photovoltaic technology. (The first report, AP-2544, was issued in August 1982.) Performance data from five flat-plate and five concentrator systems are presented and interpreted. The contractor is Boeing Computer Services Co. *EPRI Project Manager: R. W. Taylor*

COAL COMBUSTION SYSTEMS

Coal Combustion By-Products Utilization Manual: Annotated Bibliography

CS-3122 Final Report (RP1850-1), Vol. 2; $16.00

This annotated bibliography cites all the reference documents used in the preparation of Volume 1 (forthcoming), a manual that presents a decision methodology for assessing the by-product utilization option. Because the documents are categorized by keywords, the bibliography can also serve as an independent tool for literature searches. The contractor is Michael Baker, Jr., Inc. *EPRI Project Manager: R. Y. Komai*

Literature Survey of the Behavior of Materials in Ammonia

CS-3148-SR Special Report; $10.00

Anhydrous ammonia, more and more an economically attractive fluid for a heat transport or power cycle, is both toxic and corrosive; thus reliable containment is essential. In conjunction with a demonstration steam-ammonia bottoming cycle scheduled for 1985 startup, Electricité de France surveyed the literature on materials that have been used with ammonia in similar applications. This report presents the results. *EPRI Project Manager: J. A. Bartz*

Pressurized Fluidized-Bed Combustion Cycle Screening Study

CS-3151 Final Report (RP1180-13); $14.50

A study was conducted to evaluate a large number of pressurized fluidized-bed combustion plant configurations in order to identify performance trends. The focus was on thermodynamic performance. The best candidates for mid-term development and for near-term utility application are reviewed. Also described is a sensitivity study showing the effects of key parameters on the performance of the most promising cycles. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: S. G. Drenker*

Symposium Proceedings: Feed Pumps

CS-3158 Proceedings (WS81-211); $31.00

This report contains papers presented at an EPRI-sponsored symposium on the state of the art of power plant feed pumps. The papers address hydraulic design; component mechanical design; system design; and operation, maintenance, and diagnostics. The contractor is Energy Research & Consultants Corp. *EPRI Project Manager: I. A. Diaz-Tous*

Analysis of Creep Rupture Data for Five Multiheat Alloys by the Minimum Commitment Method

CS-3171 Final Report (RP638-1); $10.00

This report describes the minimum commitment method, an improved method for the extrapolation of creep rupture data. A heat centering technique is used to simplify multiheat data and facilitate the characterization of individual heats. A preliminary study shows that by using the computer programs presented here, the long-term behavior of any given heat of material can be estimated with much greater accuracy than before. The contractors are the Metal Properties Council, Inc., and Case Western Reserve University. *EPRI Project Manager: Ramaswamy Viswanathan*

Demonstration of Unsaturated and Saturated Groundwater Flow Modeling at a Coal Ash and Dry FGD Disposal Site

CS-3173 Topical Report (RP1406-1); $13.00

Two codes for predicting groundwater flow were applied to an actual flue gas desulfurization (FGD) sludge disposal site. The codes are UNSAT1D (for partially saturated flow systems) and COUPLE (for saturated and partially saturated flow systems). The report includes a thorough description of all the steps necessary to apply the codes. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: D. M. Golden*

Technical and Economic Evaluation of the Kureha Acetate Process

CS-3183 Final Report (RP982-27); $14.50

This report assesses the Kureha flue gas desulfurization process, a Japanese-developed sodium acetate–lime dual-alkali process that yields gypsum as a usable by-product. Laboratory and pilot plant data and process chemistry were reviewed to determine technical feasibility. On the basis of EPRI economic premises, a cost estimate was also prepared for a Kureha scrubber system serving two 500-MW units burning coal with 4% sulfur. The contractor is Bechtel Group, Inc. *EPRI Project Manager: T. M. Morasky*

Corrosion-Related Failures in Feedwater Heaters

CS-3184 Final Report (RP1265-11); $19.00

This report documents a literature survey conducted to characterize corrosion-related failures in feedwater heaters in terms of location, cause, frequency, and corrective actions. Recommendations for minimizing corrosion-related failures are made in the areas of design, materials selection, operation, and repair. Needed experimental studies are also identified. The contractor is

Battelle, Columbus Laboratories. *EPRI Project Manager. B. C. Syrett*

Aqueous Absorbents for Stack Gas Desulfurization by Absorption/Stripping
CS-3185 Final Report (TPS77-747); $14.50

This report discusses an experimental evaluation of several alternative aqueous absorbents for use in absorption/stripping processes for flue gas desulfurization. The absorbents studied were sodium citrate, glyoxylic acid. basic aluminum sulfate, adipic acid, and ethylenediamine. The contractor is the University of Texas at Austin. *EPRI Project Manager: D. A. Stewart*

Preliminary Analysis of 6- × 6-ft AFBC Facility Emissions
CS-3188 Final Report (RP1179-8); $17.50

This report provides preliminary data for the environmental characterization of atmospheric fluidized-bed combustion (AFBC). Gas and solid stream specimens were collected from the 6- × 6-ft AFBC facility. Analyses of these samples covered the most significant chemical, physical, and morphological characteristics. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: C. J. Aulisio*

Gas Cleaning Technology for High-Temperature High-Pressure Gas Streams
CS-3197 Annual Report (RP1336-1); $17.50

In an earlier, preliminary evaluation of high-performance devices for hot gas cleanup in pressurized fluidized-bed combustion power plants, three filters and two advanced diagnostic instruments showed promise. This report describes further performance and durability testing of these devices. The filters are a woven ceramic bag filter, a porous sintered-metal tube, and a porous ceramic candle tube; the diagnostic instruments are a developmental filter cake mass detector and a commercially available optical particle transducer. The contractor is Westinghouse Electric Corp. *EPRI Project Managers: S. G. Drenker and O. J. Tassicker*

Root-Cause Failure Analysis: Fossil-Fired Power Plant Draft Fans
CS-3199 Final Report (RP1649-6); $16.00

This report describes the collection and analysis of fan-related outage data for 61 large fossil fuel steam power plants. The outage causes are ranked in terms of their impact on production, and a systematic search for generic root causes is described. Recommendations are made for short-term corrective measures and for longer-term research efforts to significantly improve fan system reliability. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: I. A. Diaz-Tous*

High-Reliability Condenser Design Study
CS-3200 Final Report (RP1689-10); $20.50

U.S. and European condenser designs and practices were reviewed in order to recommend improvements and further research needs. Designs for enhancing condenser integrity, deaeration, and thermal performance are discussed. Improvements in condenser-associated systems are also addressed, including macro- and micro-fouling control technologies and cooling-water pump designs. Several areas for research are identified. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: I. A. Diaz-Tous*

Advanced Rotor-Bearing Systems for Feedwater Pumps: Hardware Design and Fabrication
CS-3203 Final Report (RP1884-4); $10.00

This report summarizes the third phase of an ongoing effort to develop component hardware to reduce feedwater pump vibration problems. The work covered here includes the design of high-damping rotor-support hardware components and the construction of an apparatus for testing these components. The contractors are Maurice L. Adams, Jr., and Energy Research & Consultants Corp. *EPRI Project Manager: I. A. Diaz-Tous*

TEFERI: Numerical Model for Calculating the Performance of an Evaporative Cooling Tower
CS-3212-SR Special Report; $10.00

Today's computers enable utility designers to predict the performance of evaporative cooling towers with great accuracy by using the Poppe formulation, a substantial improvement over earlier methods. This report documents the digital code TEFERI, developed by Electricité de France for solving the Poppe formulation rapidly and at a relatively small cost. A user's guide and a FORTRAN listing are included. *EPRI Project Manager: J. A. Bartz*

Basic Studies to Reduce Electrostatic Precipitator Size and Cost
CS-3226 Interim Report (RP533-1); $14.50

Laboratory and bench-scale tests were conducted to gain a better scientific understanding of several processes basic to ESP performance: collecting-plate rapping, electromechanics of ash layers, particle transport and gas dynamics, and ash deposition and reentrainment. Also investigated were these new concepts in particulate collection: agglomeration in alternating electric fields, triode collectors for high-resistivity ash, and electrified granular bed filters. The contractor is Stanford University. *EPRI Project Manager: Walter Piulle*

Recommended Guidelines for the Operation and Maintenance of Feedwater Heaters
CS-3239 Final Report (RP1887-3); $14.50

Failures of feedwater heaters continue to have a significant adverse effect on the availability and thermal efficiency of both fossil fuel and nuclear power plants. These guidelines discuss the main causes of such failures and make recommendations for improving heater operation and maintenance. The contractor is International Energy Associates, Ltd. *EPRI Project Manager: I. A. Diaz-Tous*

ELECTRICAL SYSTEMS

Analysis Techniques for Power Substation Grounding Systems: User's Manual
EL-2682-CCM Computer Code Manual (RP1494-2), Vol. 2; $13.00

This easy-to-use manual presents the first efficient and economical computer program for accurately analyzing complex substation grounding grids. It introduces basic concepts, defines terms, documents the program, and guides the reader step by step through a sample analysis. The contractor is the Georgia Institute of Technology. *EPRI Project Manager: J. H. Dunlap*

Gapless Surge Arresters for Power Systems Applications
EL-3166 Final Report (RP657-1, -2, -3); Vol. 1, $22.00; Vol. 2, $10.00; Vol. 3, $8.50

Eliminating gaps from surge arrester designs allows better controlled, more reliable, and less costly power transmission. Extensive testing has resulted in the successful development of a gapless zinc oxide ceramic arrester, now commercially available. Volume 1 describes the development of this innovative design, Volume 2 describes field tests of 1200-kV arresters, and Volume 3 describes field tests of 500-kV arresters. The contractors are Westinghouse Electric Corp., the Bonneville Power Administration, and the Tennessee Valley Authority. *EPRI Project Manager: V. H. Tahiliani*

Design and Economic Evaluation of Higher-Strength and Corrosion-Resistant Generator Retaining Rings
EL-3169 Final Report (RP1876-1), Vol. 1; $11.50

Design and economic analyses were conducted to quantify the benefits of using higher-strength, corrosion-resistant retaining rings in large electric generators. The effects of high-strength-ring generator designs on efficiency and electrical system performance were assessed. The failure probability of the currently used 18Mn-5Cr rings was studied, and the economic value of materials with a greater resistance to corrosion and stress corrosion cracking was estimated. The contractor is General Electric Co. *EPRI Project Managers: Ramaswamy Viswanathan and D. K. Sharma*

EMP Analysis
EL-3172 Final Report (SIA82-417); $11.50

This report assesses the status of research relating to electromagnetic pulse (EMP) effects on electric power systems and analyzes the viability of one sensitive system element—protective relaying and controls. It presents recommendations for research complementary to federal efforts to give industry timely indications of the vulnerability of existing power systems to EMP attack. The status of federal government–industry emergency preparedness planning for nuclear attack is examined, and steps for revitalizing an earlier plan are suggested. The contractor is Electric Research & Management, Inc. *EPRI Project Manager: Mario Rabinowitz*

Development of Improved Linemen's Protective Equipment: Phase 1
EL-3208 Final Report (RP2239-1); $14.50

In surveys at 14 utilities that experience climate extremes, linemen ranked greater durability and flexibility, comfort, and ease of use as the improvements most needed in their protective equipment (e.g., leather gloves, rubber insulating gloves, sleeves, blankets, line hose, and covers). Through a literature review, interviews with manufacturers, and idea generation sessions, the most promising new materials and technologies were selected; a preliminary evaluation of their effectiveness, cost, and availability was conducted. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: R. S. Tackaberry*

Workshop Proceedings: Retaining Rings for Electric Generators

EL-3209 Proceedings (RP1876); $26.50

The failure of generator retaining rings can cause extensive machine damage and lengthy forced outages. An EPRI-sponsored workshop examined specific cases of ring failure, outlined current procedures for detecting and minimizing stress corrosion cracking, and reviewed some promising new ring materials. *EPRI Project Managers: Ramaswamy Viswanathan and D. K. Sharma*

Explosive Compaction of Amorphous Ferromagnetic Metal Powders

EL-3215 Final Report (TPS82-610); $10.00

Excellent soft magnetic properties make amorphous alloys attractive for several utility applications, but their ribbon form presents manufacturing problems. This study explored explosive compaction as a means of producing bulk-form amorphous metal while retaining the magnetic properties of the ribbon. The contractor is SRI International. *EPRI Project Manager: Mario Rabinowitz*

ENERGY ANALYSIS AND ENVIRONMENT

Application of ALPHA-1 Plume Model Validation and Development: Plains Site

EA-3073 Final Report (RP1616-11); $10.00

An airborne lidar plume and haze analyzer (ALPHA-1) was used to make measurements of the plume of the Kincaid station near Springfield, Illinois. The data—vertical cross-sectional scans of aerosol scattering from the surface to the aircraft's altitude (typically about 10,000 ft)—were used to map the position and shape of the plume downwind from the plant. Results from this and other data collection experiments will be used to develop new and more valid computer models of effluent dispersion. The contractor is SRI International. *EPRI Project Manager: G. R. Hilst*

EPRI Plume Model Validation and Development Project and Experimental Design: Plains Site

EA-3075 Final Report (RP1616-1); $11.50

This report describes the site selection and the development of an experimental design for field studies of stack emission dispersion from a generating plant on flat terrain. The data gathered from such experiments will be used to develop new plume models for computer analysis of power plant emissions. The contractor is TRC Environmental Consultants, Inc. *EPRI Project Manager: G. R. Hilst*

Second-Order Closure Model Exercise for the Kincaid Power Plant Plume

EA-3079 Final Report (RP1616-9); $19.00

This report reviews a second-order closure model for plume dispersal and analyzes how available meteorologic data are used as model input. Model simulations are given for 10 periods when meteorologic conditions were judged sufficiently steady for the model to be valid. Model results are compared with surface sampler data for daytime conditions and with plume distribution data from remote sensors for nocturnal conditions. The contractor is Aeronautical Research Associates of Princeton, Inc. *EPRI Project Manager: G. R. Hilst*

Estimates of Uncertainty for the Plume Model Validation and Development Project Field Measurements: Plains Site

EA-3081 Final Report (RP1616-10); $16.00

This report describes an external, third-party quality assurance program conducted to establish the reliability and usefulness of EPRI's plume model validation and development project, which is designed to measure pollutant emissions from power plants. The contractor is Research Triangle Institute. *EPRI Project Manager: G. R. Hilst*

ETA-MACRO: Progress Report

EA-3170 Interim Report (RP1014); $19.00

This report documents recent work with ETA-MACRO, a computer model designed to estimate the extent of two-way linkage between the energy sector and the balance of the economy. Two new features that increase application flexibility—a variable time horizon submodel and a load duration submodel—are described. An experiment that used 1970–1980 U.S. data to estimate two key model parameters is discussed, as are international applications of the model. The contractor is Stanford University. *EPRI Project Manager: S. K Mukherjee*

Statistical Comparison of Two Studies on Trace Element Composition of Coal Ash Leachates

EA 3181 Final Report (RP1487); $11.50

This report describes a statistical analysis of data from two studies that measured trace element concentrations in extracts of ash from coal-fired power plants. Both studies involved the replication of sample preparation (extraction) and analytic procedures at multiple laboratories. The statistical analysis was undertaken to evaluate the reproducibility of these procedures and to assess how variations in the different steps affected the results. The contractors are Barry Eynon and Paul Switzer. *EPRI Project Manager: I. P. Murarka*

Regional Electric Utility Fuel Markets: Gulf, Central South, and Southeast States

EA-3210 Final Report (RP1981-10); $23.50

Utility planning for generating facilities and fuel procurement must accommodate uncertainties in both regional and national fuel markets. This thorough analysis of emerging markets in the Gulf Coast region examines the implications of market fluctuation for utility planners, with a focus on competition between gas and oil. The contractor is Charles River Associates, Inc. *EPRI Project Manager: Jeremy Platt*

Analysis of Risky Investments for Utilities

EA-3214 Final Report (TPS82-636); $11.50

Taking risk into account is important in assessing the real value of a utility's investments. This report describes three specific approaches that can help utilities define risk levels for different types of investments before reaching a capital commitment decision. The contractor is Charles River Associates, Inc. *EPRI Project Manager: Dominic Geraghty*

Fate of Atmospheric Emissions Along Plume Trajectories Over the North Sea: Summary

EA-3217 Final Report (RP1311-1); $16.00

Tracking the fate of power plant plumes would enable utilities to evaluate the role of fossil fuel emissions in acidic precipitation. Cloud chemistry, tracer, and aircraft instrumentation technologies developed in this project now make it possible to measure in-cloud chemistry and the long-range transport of pollutants from a specific source. The contractor is the Central Electricity Research Laboratories (England). *EPRI Project Manager: G. R. Hilst*

Physical-Chemical Characteristics of Utility Solid Wastes

EA-3236 Final Report (RP1487-12); $20.50

Solid residues from coal-burning power plants, deposited in landfills and ponds, are expected to total 100 million tons annually by the year 2000. Data are needed on the chemical composition of these wastes and on the substances that leach from them. This report describes a project to evaluate existing information on solid-waste composition for use in indentifying potential leachates. The contractor is Tetra Tech, Inc. *EPRI Project Manager: I. P. Murarka*

End-Use Meter: Development and Design of the Electric ARM

EA 3247 Final Report (RP1589-1); $13.00

Utilities need customer appliance load curve data for a wide range of planning functions, but conventional methods of metering individual appliances are costly and inconvenient. The Electric ARM (appliance research metering) system, now available commercially, eliminates rewiring and is a cost-effective way to collect end-use data. This report provides details on the circuitry, software, and design of the system. The contractor is Robinton Products, Inc. *EPRI Project Manager: Edward Beardsworth*

ENERGY MANAGEMENT AND UTILIZATION

Description of a Generic 11-MW Fuel Cell Power Plant for Utility Applications

EM-3161 Interim Report (RP1777-1); $16.00

Commercialization of phosphoric acid fuel cell technology is expected in the late 1980s. The power plant configuration described in this report is a significant milestone in that effort. The comprehensive documentation will enable utilities to conduct preliminary cost and performance analyses and will give manufacturers a strong basis for detailing plant and component designs. The contractor is United Technologies Corp. *EPRI Project Manager: D. M. Rastler*

Energy Conservation Through Reduction of Air Infiltration in Electrically Heated Houses

EM-3175 Final Report (RP1351-1); $13.00

This report describes field investigations of retrofit measures to reduce air leakage in electrically heated houses in the Denver, Colorado, area. It discusses the effects of the retrofit measures, as well as of energy conservation practices and changes in lifestyle, on air leakage and electric energy use. The contractors are Manville Service Corp. and Public Service Co. of Colorado. *EPRI Project Manager: Arvo Lannus*

Application of Fuel Cells on Utility Systems
EM-3205 Interim Report (RP1677-6); Vol. 1, $11.50; Vol. 2, $13.00

As documented in Volume 1, conventional system planning analyses using data from 25 diverse U.S. utilities indicate that phosphoric acid fuel cell power plants can be a competitive option for generation expansion between 1986 and 2005. The study data and approach bring a new credibility to the analysis of this technology. Volume 2 presents a fully documented workbook that utilities can use to assess the costs and benefits of including fuel cell power plants in their generation plans. The contractor is Energy Management Associates, Inc. *EPRI Project Manager: D. M. Rigney*

Simplified Methodology for Economic Screening of Potential Small-Capacity Hydroelectric Sites
EM-3213 Final Report (RP1745-8); $22.00

The rising costs of electric power production have focused attention on certain resources, such as small-capacity hydroelectric sites, that were previously thought to be uneconomic or too limited for development. This revised manual presents procedures that utilities can use to expedite the preliminary screening of potential sites. The contractor is Tudor Engineering Co. *EPRI Project Manager: C. W. Sullivan*

NUCLEAR POWER

Nuclear Steam Supply System Transient Tests at ANO-2: Revision 1
NP-1708 Final Report (RP1385-1); $23.50

Experimental data from power plant tests of nuclear steam supply system transients increase the credibility of computer code simulations designed to demonstrate compliance with NRC design-basis-event criteria. This revision corrects and clarifies data presented in the original publication on transient tests at Unit 2 of Arkansas Nuclear One. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: J. A. Naser*

Laboratory Studies Related to Steam Generator Tube Denting
NP-3023 Final Report (RPS112-1); Vol. 1, $17.50; Vol. 2, $32.50

This report documents laboratory work to reproduce the denting phenomenon observed in some steam generator heat transfer tubing and then to determine the effectiveness of selected candidate additives with regard to their ability to inhibit denting. Boric acid, calcium hydroxide, and sodium phosphate were evaluated for their effectiveness in controlling corrosion. Volume 1 summarizes the work; Volume 2 presents detailed test results. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. P. N. Paine*

Sodium Sulfate Solubilities in High-Temperature Salt and Acid Solutions
NP-3047 Final Report (RP623-5); $11.50

Results are presented from a study designed to characterize sodium sulfate and sodium chloride solutions occurring in PWR steam generator crevices. This work entailed (1) determining solubility through direct experimentation at elevated temperatures (250–374°C), and (2) modeling the pH and boiling point elevation of the resultant solutions. Two diagnostic computer programs were developed for easy application to power plant operation. The contractor is Oak Ridge National Laboratory. *EPRI Project Managers: M. J. Angwin and J. P. N. Paine*

Optimization of Metallurgical Variables to Improve Corrosion Resistance of Inconel Alloy 600
NP-3051 Final Report (RP1708-1); $25.00

This report discusses the corrosion performance and characterization of thermally treated and mill-annealed alloy 600 tubing. The project objectives were to confirm that special thermal treatment improves the alloy's resistance to stress corrosion cracking (SCC); to develop a model for improved SCC resistance; to define carbide dissolution and precipitation kinetics; to evaluate the long-term low-temperature microstructural changes in the alloy; and to establish suitable stress relief annealing parameters. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. E. Shoemaker*

Engineering and Probabilistic Analysis of Tube Cracking Performance in OTSGs
NP-3065 Final Report (RPS151-1); Vol. 1, $13.00; Vol. 2, $26.50

This report documents an engineering and probabilistic analysis to model the dominant factors affecting tube cracking in the upper region of some once-through steam generators (OTSGs). Volume 1 summarizes the modeling technique and its application. Volume 2, which is available in limited quantities, provides a detailed archival record of the data and analyses. The contractor is Failure Analysis Associates. *EPRI Project Manager: D. A. Steininger*

Testing and Analysis of Feedwater Piping at Indian Point-1: Damping and Frequency
NP-3108 Final Report (RP964-2, -3, -4), Vol. 1; $43.00

In situ tests were conducted to develop a data base for investigating piping-system dynamic characteristics and response behavior. This volume focuses on damping values, frequency characteristics, insulation effects, nonlinear behavior, and analytic correlations in terms of response levels and support configurations. The contractors are Consolidated Edison Co. of New York, Inc.; EDS Nuclear, Inc.; and Anco Engineers, Inc. *EPRI Project Manager: Y. K. Tang*

LWR Core Materials Performance Program: Progress in 1981–1982
NP-3150-SR Special Report; $14.50

This progress report for the LWR core materials performance program describes projects ranging in scope from test reactor experiments of advanced fuel types to large-scale testing of prototypic fuel assemblies. During 1981 and 1982 several projects produced significant results. The primary emphasis continues to be on fuel reliability, with demonstrations of extended fuel burnup capability receiving significant support. *EPRI Project Managers: D. Franklin, S. Gehl, A. Machiels, and J. Santucci*

Modeling Air-Water Tests With DUVAL
NP-3163 Final Report (RP963-3); $8.50

This report examines the ability of the DUVAL computer code to model two-dimensional, two-phase flows in air-water mixtures. DUVAL predictions are compared with data from air-water experiments; the conservation equations simulating the flows are documented in detail. The comparisons indicate that DUVAL can accurately simulate such air-water experiments without heat addition. The contractor is the University of Pittsburgh. *EPRI Project Manager: P. G. Bailey*

Assessment, Development, and Application of LMFBR Thermal-Hydraulic Analysis Tools
NP-3167 Final Report (RP620-39); $14.50

The whole-core LMFBR thermal-hydraulic codes COBRA-WC, COMMIX, CORE-3D, CORTRAN, and SUPERENERGY-2 were evaluated from the design analyst's perspective. Basic algorithms, code capabilities, physical models, user instructions, and general features were considered. An expanded version of CORTRAN was developed and applied to the analysis of split inlet plenum designs. Orificing strategies for these designs were investigated. The contractor is Barthold & Associates, Inc. *EPRI Project Manager: A. G. Adamantiades*

Semiautomatic Weld Crown Contouring Equipment
NP-3168 Final Report (RPT120-1); $8.50

This report summarizes a project to develop and build a field-ready, working prototype of a semiautomatic weld crown contouring device. The prototype developed, a microprocessor-controlled external lathe, satisfied all the specified design criteria and accommodated pipe diameters ranging from 8 to 30 inches. The contractor is Sigma Research, Inc. *EPRI Project Manager: G. J. Dau*

Development of LOMI Chemical Decontamination Technology
NP-3177 Final Report (RP1329-1); $19.00

This report describes the development of low-oxidation-state metal-ion (LOMI) reagents, which dissolve oxides rapidly without affecting the underlying metal. The application of these reagents to PWR and BWR decontamination is discussed. One of the reagents, vanadous picolinate/formate, appears to have good radiation stability, and its released activity can be collected conveniently on ion-exchange resins. The contractor is the Central Electricity Generating Board (England). *EPRI Project Manager: R. A. Shaw*

Nuclear Power Plant Fire Loss Data
NP-3179 Final Report (TPS81-826); $13.00

Fire loss data were collected for 59 incidents in operating nuclear plants for the period January 1978–February 1981. This report analyzes the data and breaks the incidents down into nine categories. The results are compared with those from an earlier study, and several significant differences are noted. Recommendations for improved, continual reporting of nuclear plant fire loss data are included. The contractor is Professional Loss Control, Inc. *EPRI Project Manager: Joseph Matte III*

Thermal-Hydraulic Characteristics of a Heat-Generating Bed Under Forced-Flow Cooling Conditions

NP-3180 Interim Report (RP1931-1); $13.00

This report examines the coolability of a heat-generating debris bed under forced-flow conditions. It presents the results of experiments to determine pressure drop and temperature distribution when the maximum bed temperature is near the fluid saturation temperature. The contractor is the University of California at Los Angeles. *EPRI Project Manager: David Squarer*

Feasibility of Surface Inspection Automation

NP-3186 Final Report (RP1395-6); $10.00

This report presents an evaluation of surface inspection techniques for the in-service examination of reactor vessels and reactor internal attachments. The special needs and problems of the nuclear industry are analyzed, and laboratory experiments that examined the feasibility of using microencapsulated fluorescent penetrants are described. The contractor is Science Applications, Inc. *EPRI Project Manager: M. E. Lapides*

Development of a Crack Growth Algorithm for Time-Dependent Analysis of Steam Turbine Rotors

NP-3187 Interim Report (RP1570-2); $8.50

This report presents a data base of published and unpublished information on the rate of high-temperature creep crack growth in 1Cr-Mo-V steel. It also describes the development of a calculational procedure for use in predicting creep crack growth that is suitable for incorporation into SAFER or similar turbine rotor lifetime prediction codes. The contractbr is J. A. Jones Applied Research Co.; the subcontractor is Failure Analysis Associates. *EPRI Project Manager: G. J. Dau*

Analysis of Test Lattice Experiments in the Light Water High-Conversion Reactor PROTEUS

NP-3190 Final Report (RP1074-4); $10.00

This report describes the preliminary analysis of a series of tight-pitch lattice experiments conducted at the PROTEUS zero-power reactor facility in Switzerland. Data are presented on a PuO_2/UO_2-fueled test lattice with a fuel-to-moderator ratio of approximately 2.0. Measurements include the capture rate in U-238 and fission rates in U-235, U-238, Pu-239, and Pu-241 The contractor is Torrey Pines Technology. *EPRI Project Manager: Odelli Ozer*

Reflooding of a Vertical Tube at 1, 2, and 3 Atmospheres

NP-3191 Final Report (RP248-1); $14.50

This report documents an experimental study of the effect of pressure on the reflooding of a single vertical tube simulating a single core flow channel. The experiments were performed at pressures of 1, 2, and 3 atm, the expected conditions of a large-break loss-of-coolant accident. Quench front histories, heat transfer coefficients, and effluent characteristics are reported, and the data are compared with previous results. The contractor is the University of California at Berkeley. *EPRI Project Manager: Loren Thompson*

BWR Hybrid Power Shape Monitoring System: Version 2.0

NP3195-CCM Computer Code Manual (RP1442); Vol. 1, $23.50; Vol. 2, $20.50; Vol. 3, $34.00; Vol. 4, $14.50; Vol. 5, $16.00

Second-generation modifications that provide greatly simplified operation, fast predictive ability, continuous self-correction, and complete documentation have made the BWR PSMS core monitoring system a powerful tool for utility use. This five-volume report documents the system, which is now available and which offers great advantages in plant operating control and flexibility over conventional interpretive monitoring systems. The contractors are Systems Control, Inc.; Nuclear Associates International; and Hitachi Ltd. *EPRI Project Manager: A. B. Long*

Computations of the Fluid Annulus Surrounding a Pump Shaft in Synchronous Vibration

NP-3201 Final Report (RP2014-2); $10.00

A study was conducted to examine the fluid forces that arise from the fluid annulus surrounding a pump shaft in synchronous vibration. A computation method based on the STEALTH 2D code was used to analyze pump shaft synchronous vibrations in two flow regimes. Both infinitesimal (perturbation) and finite (substantial) shaft displacement were investigated. The contractor is Science Applications, Inc. *EPRI Project Manager: Conway Chan*

Added Mass Computation for Impellers in Nuclear Power Pumps

NP-3202 Final Report (RP2014-1); $11.50

This report documents a study of fluid forces in the impeller region of a pump. It describes the development of a method for calculating the effect of the hydrodynamic mass on the impeller. In contrast to previous approaches, this method includes an accurate, three-dimensional representation of the impeller shape and the pump geometry and accounts for the effects of fluid velocity. The contractor is Northwestern University. *EPRI Project Manager: Conway Chan*

Workshop Proceedings: Replacement/Repair of Steam Generators

NP-3207-SR Special Report; $17.50

The repair or replacement of PWR steam generators has become an important consideration for owners. EPRI sponsored a two-day workshop for representatives of utilities, nuclear steam system suppliers, architect-engineers, builders, and consultants to address this issue. Among the topics discussed were the experience of two utilities that have replaced steam generators, the experience to date with available sleeving techniques, and planning for repairs and replacement. *EPRI Project Manager: J. A. Mundis*

Scoping Thermal Analysis of the Three Mile Island Unit 2 Pressure Boundary

NP-3211 Final Report (RP2056-1); $13.00

This report documents a series of exploratory thermal analyses performed for several regions of the Three Mile Island Unit 2 pressure boundary. An estimate of the thermal response of the pressure boundary components to the partial core uncovery accident is included. Recommendations are discussed for using the results of this work as input in a subsequent stress analysis and for identifying those regions that will require detailed analysis. The contractor is General Electric Co. *EPRI Project Manager: S. W. Tagart, Jr.*

Cobalt Contamination Resulting From Valve Maintenance

NP-3220 Final Report (TPS81-814); $13.00

Valve maintenance operations, particularly seat grinding, can introduce substantial quantities of cobalt-containing debris into the piping systems of LWRs: This report recommends simple and easily implemented control measures that can markedly reduce this major potential source of personnel radiation exposure. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: M. D. Naughton*

Proceedings: 1983 ASME–EPRI Radwaste Workshop

NP-3222 Proceedings (RP1557); $13.00

This fifth ASME–EPRI workshop provided an update on how utilities are handling liquid radwaste disposal. Workshop speakers reviewed disposal techniques, waste volume control, the processing of wastes during major outages, and the site-specific nature of radwaste disposal problems. The new reporting requirements of regulation 10CFR61 were also discussed. The contractor is BVC Consultants, Inc. *EPRI Project Manager: M. D. Naughton*

Determination of Waste Container Curie Content From Dose Rate Measurements

NP-3223 Final Report (RP1557-7); $14.50

This report describes the development of DOSCON, a computer program written in FORTRAN IV to calculate radwaste package millicurie content from the observed dose rate and relative radionuclide distribution. Details are provided on the benchmarking of DOSCON against a waste package, and gamma attenuation coefficients for dewatered resins and cemented wastes are determined. The contractor is NWT Corp. *EPRI Project Manager: M. D. Naughton*

Assessment of Power Reactor Waste Immobilization by Vitrification

NP-3225 Final Report (RP1557-8); $16.00

This report describes a study that assessed the technical, economic, and safety aspects of applying vitrification, a one-step volume-reduction process, to low-level radioactive waste from a nuclear power plant. A conceptual design of a vitrification facility for normal waste processing at a nuclear plant was developed. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: M. D. Naughton*

Guide to Qualification of Electrical Equipment for Nuclear Power Plants

NSAC-58 Final Report; $10.00

This report is a guide to the overall process of electrical equipment qualification. It outlines the documentation required and extensively discusses testing as a method of qualification. The contractors are Baltimore Gas and Electric Co., Commonwealth Edison Co., Duke Power Co., Impell Corp., Engineering Planning & Management, Franklin Research Center, Philadelphia Electric Co, and Wisconsin Electric Power Co. *EPRI Project Manager. R. N. Kubik*

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