Decision Maps

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Cover: Decision makers are turning to the formal procedures of decision analysis to chart the best possible route through a complex decision.

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Decisions: Right, Wrong . . . or Rational?

Making good decisions has always been the hallmark of an effective executive. Decisions in the management of a utility characteristically involve very large amounts of money and result in actions that have very long-lasting consequences. The utility decision maker's view must extend far into the future to deal with such questions as how much new capacity will be needed, what power generation technology will be best suited to the utility's needs, and when and where to build a plant. As inherently difficult as these questions are, growing uncertainty about the future—the environment in which decisions made today will have to exist—has made the task even harder.

Of course, the uncertain future has been the thorn in the decision maker's side in every era. But the last decade has brought surprises in areas that form the very foundation of utility planning: declining growth in electricity demand, escalating costs of fuel and capital, and routine delays in plant licensing and construction. With so many factors departing strongly from patterns that were long considered steady and predictable, even if the future is actually no less certain than before, it appears much less certain to the decision maker.

It is for this reason that a new approach to analyzing decisions has been adapted for use by the utility industry. Decision analysis is an approach for evaluating options that explicitly takes uncertainty into account. This is not to say that the traditional decision maker did not consider uncertainty implicitly as he turned over the options in his head. But as the problem becomes more complicated, there is a point beyond which all the options, all the factors affecting the outcomes of these options, and all the possible measures of the outcome cannot be held in one's head simultaneously. It is at this stage that the mathematical techniques of decision analysis, which parallels the thinking process and gives it structure, can be particularly useful.

Along with the growing complexity of the modern world has come another relatively recent development—an increasing public scrutiny of decisions, past and present, and a growing expectation of accountability. Whether he reports primarily to a board of directors, stockholders, government bodies, customers, or the public at large, the decision maker finds himself facing a great deal of pressure. He must make his decisions before all the facts are in, but he must also be able to justify what may eventually come to be seen as the wrong decision. Given a good measure of hindsight and new data, any number of Monday morning quarterbacks will be able to confidently point out what the right decision should have been.

Herein lies the crux of the decision maker's problem: right and wrong are value judgments made after the fact and have little to do with the decision-making process. It is as far as we can go to make the best decision for the time with the facts available—a *rational* decision, one that can be explicated clearly and shown to correspond well with the information then at hand.

Here again, the decision analysis tool is particularly well suited to the task. Not only does it provide a framework for breaking large decisions down into smaller, more manageable decisions but it also leaves a permanent record of how all the considerations and assumptions were taken into account. Along the way, this technique helps clarify options, draws sharper distinctions among differing opinions, and reveals the assumptions to which the decision is most sensitive.

But aside from its technical capabilities, perhaps the most striking attribute of the decision analysis technique is its versatility of application. This aspect is pointed up clearly in the examples cited in this month's lead story. One case deals with a traditional utility system expansion problem; another involves determination of the best R&D strategy for a new technology; in a third, strategy for environmental research is the issue. Decision analysis has worked well in these and countless other applications both inside and outside the utility industry.

However, it is not an answer machine. The analyst's job only goes so far: to arrange the raw materials of a decision in such a way as to define the options as clearly as possible. The responsibility for assumptions and judgments still remains firmly with the decision maker himself. He must continue to make estimates of future conditions, choose which are the most important measures, and decide what risks are appropriate to carry.

Thus, decision analysis will not relieve the decision maker of responsibility. What it can offer is an assurance to himself and others that whatever the quality of the available information, the decision made will be one that deals with this information in a thoughtful, rational way.

René Malès, Director
Energy Analysis and Environment Division

Authors and Articles

Subjective judgments have to play a large part in utility investment decisions when the economic future is uncertain. But how can you document and evaluate intuition or common sense? **A Roadmap for Complex Decisions** (page 6) explains an explicit, logical approach that can be helpful even in decisions on new power plants, which have combined lead times and economic lifetimes of nearly half a century.

For background on EPRI's research and early application of decision analysis, science writer John Douglas conferred with Richard Richels, an operations researcher with EPRI's Energy Analysis and Environment Division since August 1976. For the last year and a half he has been technical manager of the division's work in decision methods and analysis. Before joining EPRI, Richels was a consultant to The Rand Corp. and the National Science Foundation. Much of his work dealt with the effects of uncertainty on the planning and conduct of energy research. With a BS in physics and an MS in industrial engineering, Richels taught for four years before earning MS and PhD degrees in operations research at Harvard University.

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During the last 10 years, fabric filtration has come from nowhere to become a routinely selected means to remove fly ash from power plant exhaust gases. Why this is so, what part EPRI research has played, and what refinements are under investigation and test today are reviewed in **Particulates: Caught at the Filter Line** (page 14). The article was written by William Nesbit, science writer, aided by EPRI's Robert Carr.

Manager of the Air Quality Control Program since April 1982, Carr first came to the Institute in March 1974 and has specialized since then in particulate measurement and control. Between 1972 and 1974 Carr was a test engineer with KVB, Inc., consulting with utilities on emission controls. Before that he was a research assistant on emission measurement and analysis at the University of California at Berkeley, where he earned BS and MS degrees in mechanical engineering.

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Extensive interconnection of utility systems continues to produce the benefits of greater reliability and more-economical electricity transfer. But it is also putting pressure on the capabilities of the human and machine controllers that must handle ever greater volumes of control data. **Nerve Center for Network Control** (page 22), by Taylor Moore, *Journal* feature writer, surveys the R&D solutions afoot in such control matters as data processing speed, data display, and artificial intelligence. For technical guidance, Moore drew on two members of the Power System Planning and Operations Program in EPRI's Electrical Systems Division.

Robert Iveson has managed the program since April 1979, concentrating on the development of computer methods and programs for utility application. Iveson previously was with New York State Electric & Gas Corp. for 20 years, including 8 years as supervisor of transmission planning at the New York Power Pool. He holds BS and MS degrees in electrical engineering from Rensselaer Polytechnic Institute and Syracuse University, respectively.

Charles Frank, project manager, has been with the program since July 1976. His earlier experience includes 5 years with Landis and Gyr in utility control system software development; 5 years with General Motors Corp. in computer methods for the inertial guidance of aerospace vehicles; and 10 years at the research center of Westinghouse Electric Corp., where he developed programs for use in power system operations. Frank graduated in electrical engineering from Purdue University. He earned MS and PhD degrees in the same field at the University of Pittsburgh.

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Helium is well established as an element for tracing gas flows in industrial apparatus. **The Helium Approach to Leak Detection** (page 28) traces the R&D path that has adapted helium detection for finding leaks in the closely spaced tubes of power plant steam condensers. Carrie McKee wrote the article; EPRI's Michael Kolar and John Mundis furnished technical assistance.

Kolar has been with the Nuclear Power Division since 1978, since 1980 in the Engineering and Operations Department, where he manages the Systems Performance Program. Previously with the architect-engineer firm of Gilbert/Commonwealth for five years, Kolar managed analyses dealing with power plant safety, seismic provisions, and piping design. Earlier, he taught mathematics at Cleveland State University for four years, following seven years at NASA, Lewis Research Center. Kolar has BS and MS degrees in physics from John Carroll University and a PhD in engineering from Case Western Reserve University.

John Mundis came to the Nuclear Power Division in 1976 and has been with the Steam Generator Project Office since 1977. He is now manager of the Plant Engineering, Operations, and Maintenance Program. Mundis was previously with Bechtel Power Corp. for two years as assistant supervisor of a nuclear engineering group. From 1963 to 1974 he was a naval officer, holding engineering and operations positions on three nuclear-powered submarines and at a training facility. Mundis is a chemical engineering graduate of Rice University and has an MBA from the University of Santa Clara.


Carr


Kolar

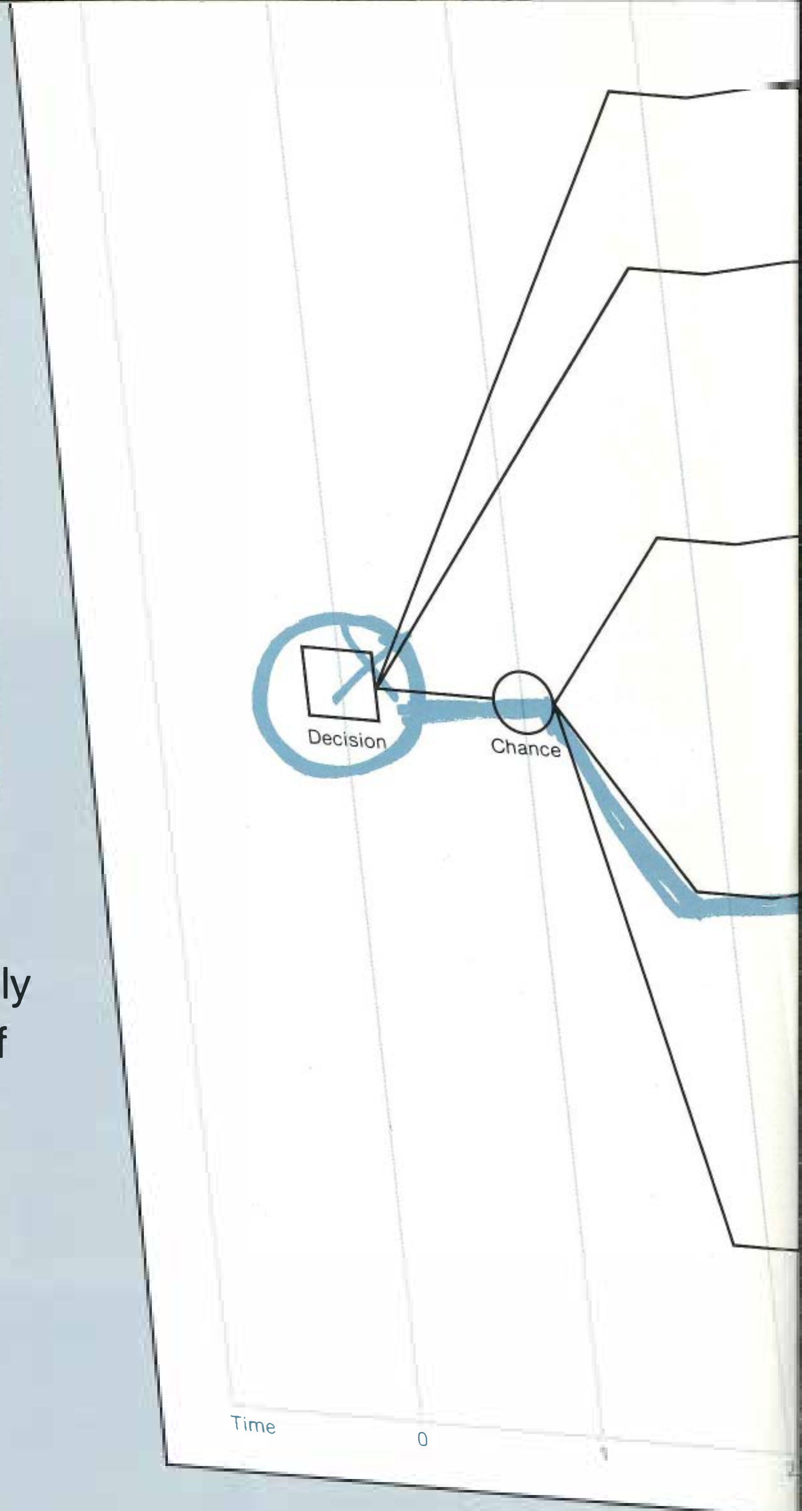

Mundis


Frank


Richels

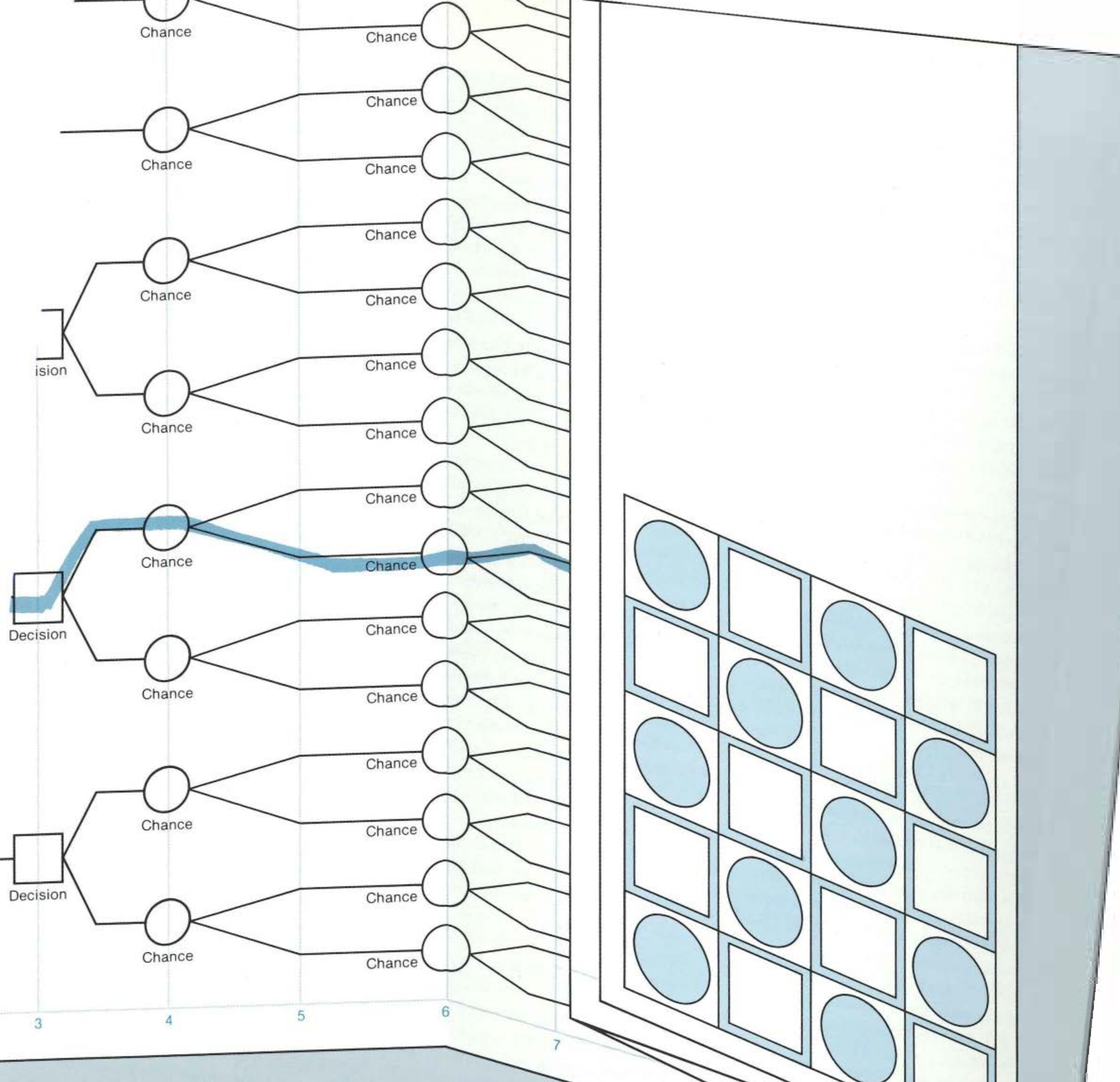

Iveson

A ROADMAP FOR COMPLEX DECISIONS



Decision makers need a way of capturing the essence of complex problems, and they are increasingly turning to the formal techniques of decision analysis to frame critical decisions— ranging from national policy to building a power plant.

Recently, when Baltimore Gas and Electric Co. (BG&E) began to consider whether to build a new generating facility, it soon became clear that many uncertainties would have to be taken into account. Load growth projections were being revised frequently; regulations were changing; and new technologies promised possible advantages by the time the plant would go on-line in the early 1990s. "These kinds of decisions are always based on fewer data than you'd like to have," recalls Christopher H. Poindexter, BG&E vice president for engineering and construction. "If you wait until you have all the information, you don't make the decision."



To make matters worse, increasingly difficult value judgments and trade-offs also had to be made. These involved such intangible factors as public attitudes, perceived health and safety advantages of alternative technologies, and a variety of environmental impacts. "There's always a gut feeling, based on experience, involved in a final decision," Poindexter says, and such feelings must be taken into account even in complex decisions.

To expedite the decision-making process in the face of such difficulties, BG&E tried a relatively new analysis technique as a test case utility in an EPRI project. Called decision analysis, the technique involves preparing a decision tree in which each uncertainty is shown explicitly. Technical experts from different disciplines are then asked to estimate probabilities for specific unknowns, while top decision makers assign relative values to various trade-offs. Finally, a computer model is used to calculate the payoffs that could be expected for each alternative in the decision.

"Most of the people in decision-making positions at BG&E were impressed with what they saw," comments Poindexter. "Along the way I think that some of them questioned whether it was worth the effort, but when we were all finished, the mainstream of the thinking went something like this: Decision analysis structures the kinds of questions we should be asking. It provides a good framework to go back in the future and see how changes affect the decision. And it also does a good job of documenting the process we went through, so that in appearances before regulatory commissions it will be easier to respond when they ask, 'Did you consider this?' or 'Did you consider that?'"

Formalized common sense

Decision analysis is a relatively young discipline that has recently come to prominence by offering better ways to deal with the uncertainties and value judgments that generally characterize complex decisions. "It is a way to formalize common sense when things are tough," says Ralph Keeney, who for many years taught decision analysis at MIT and was principal investigator on the BG&E project. As such, decision analysis does not offer a mechanistic substitute for intuition or personal values. Rather, its methods can create a framework to accommodate different points of view when vital data are missing.

The growing importance of the technique was emphasized in a recent article, "Decision Analysis Comes of Age," in *Harvard Business Review*. According to the authors, this methodology "has emerged as a complement to older decision-making techniques, such as systems modeling and operations research. In addition to statistical decision theory, the new technology draws on psychology, economics, and social science."

Although decision analysis has come into wide use only recently, its theoretical foundations go back more than 200 years to the early mathematical analysis of lotteries. The critical link between abstract statistics and human values that eventually led to decision analysis as we know it today was provided in the late 1940s by the utility theory of mathematicians John von Neumann and Oskar Morgenstern.

At an intuitive level, what they said was this: Life is a choice among lotteries. When a person decides to take one chance as opposed to another, his choice reflects a personal preference for one set of potential risks and benefits over the other. People can be helped to express their preferences by presenting them with a series of carefully chosen hypothetical trade-offs. Using this information, one can then calculate the value (utility) individuals place on the possible outcomes of a decision they must make and can help them determine which choice offers the greatest expected utility.

Over the last decade, decision analysis has been applied with increasing success to problems in several industries and in government. When Xerox Corp. introduced a new copier a few years ago, decision analysis was able to show that only under the worst (and least likely) set of circumstances would a new facility be needed to manufacture supplies for the machine. Decision analysis gained prominence as a way to evaluate the urgency of commercializing new technologies in 1975, when it became a major factor influencing President Ford's plans for developing synthetic fuels. And in the arena of public policy, decision analysis increasingly provides a common framework for presenting different sides of an issue with strong subjective overtones. A committee of the National Academy of Sciences, for example, employed decision analysis in a study of emission control strategies.

According to Warner North of Decision Focus, Inc., who played a key role in pioneering applications in the public sector, "Decision analysis provides a way of improving communications among contending parties. By making the judgments about values and uncertainties explicit and determining how these judgments affect the decision, the analysis can help to identify where differences in judgment are most important."

Utility applications

This sort of flexible, intuitive analysis can also provide valuable insight into a variety of difficult decisions now facing the electric utility industry. The Economic and Environmental Integration Staff of EPRI's Energy Analysis and Environment Division is supporting development of the application of decision analysis tools to new problem areas and their application in utility case studies.

Three types of applications are now receiving particular attention. First, individual utilities can use decision analysis to help determine the effects of building different types of power plants at various times. The need for this sort of analysis is stimulated by considerable uncertainty about future demand, the availability of new technologies, and the different uncertainties associated with these alternative technologies. Second, these methods can also help the industry as a whole plan its R&D strategy. This effort ranges from collecting judgments from experts in a variety of fields to setting priorities for the development of new technologies, which often involve long lead times and increasingly expensive demonstrations. Third, decision analysis can help narrow the distance between opposing sides in sensitive policy debates by showing explicitly the fundamental value judgments that often lie at the heart of such disagreements.

The dilemma facing BG&E as the company began planning for a new power plant illustrates how decision

BUILDING A DECISION TREE

Decision analysis can be visualized most easily by using a tree diagram, laid out along a time axis. Such a diagram serves as a road map for solving complex problems by breaking them down into their component parts. Key decisions are shown as squares and critical uncertainties as open circles. Each path through the tree represents a possible scenario, with outcomes shown as solid circles.

This tree is a simplification of the decision analysis framework showing the options open to BG&E for building a new power plant to come on-line sometime in the 1990s. The first decision that must be made (in 1986, at the far left) is whether to use conventional coal technology for 1994 operation or to wait in the hope that better technology will be available for a plant to go on-line in 1998, which would require purchasing power from 1994 to 1998.

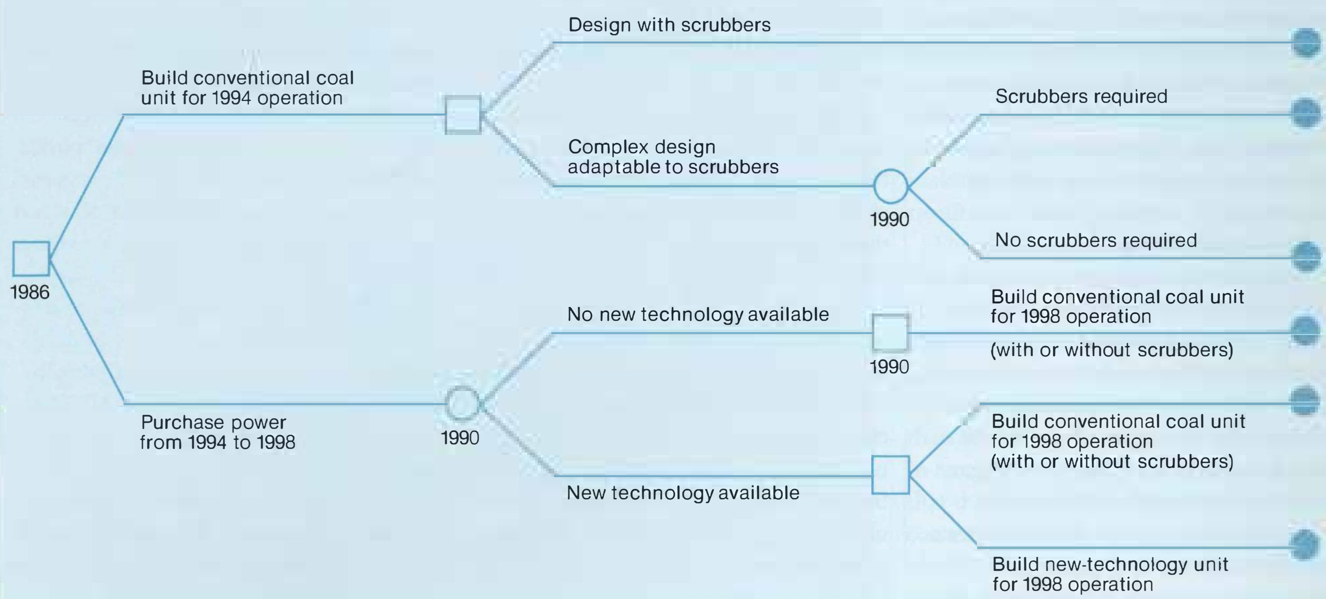
If conventional technology is chosen, another decision arises. It is possible that the utility might be able to avoid installing scrubbers by burning low-sulfur coal, but this will depend on what changes are made in environmental regulations before 1990. Thus the company must decide whether to go ahead with a plant design that includes scrubbers or to attempt a more complex design that could either take scrubbers eventually or omit them. Whether scrubbers will be required in 1990 is a key uncertainty, and probabilities for each alternative must be determined on the basis of current expert opinion.

If the utility decides to wait, 1990 then becomes the cutoff date for determining whether new technology can be used. Experts in the appropriate fields must again be asked what the probability is that each technology alternative will be available by that date. If alternatives are available, then a decision must still be made in 1990 on whether the old or the new technology appears more desirable.

Depending on what decisions are made and how uncertainties are resolved, the total cost of the new plant could vary considerably. For example, the outcome of building a conventional plant with scrubbers to enter service in 1994 would mean earlier revenue but could entail higher capital and operating costs. Waiting for new technology might mean lower costs, but if R&D proved unsuccessful, the company would have purchased power needlessly for four years.

Setting monetary values on such outcomes requires tapping the experience and expertise of a company's top decision makers. In the BG&E case, executives were asked to consider possible trade-offs—for example, choosing between better reliability and lower operating costs. From interviews involving tough questions of this sort, analysts were able to estimate eventual costs for each outcome.

Probabilities and values are then combined to indicate the expected value of each alternative open to a decision maker. This procedure is called a rollback of the tree. In the BG&E case, the result of a single rollback was an expected monetary cost for each of the two options that could be chosen in 1986. This result varied, of course, when different assumptions were made about costs and technology probabilities. □



analysis can be used by utilities to make strategic business decisions. Four main technology alternatives were being considered for use at the site—a conventional pulverized-coal plant, an atmospheric fluidized-bed facility, a KILnGAS integrated gasification–combined-cycle facility, and an IGCC facility using the Texaco gasification process. Because the last three options are not yet commercial technologies and are now at different stages of development, any choice among them depends heavily on when the new plant will be needed. However, to build what is expected to be a $1 billion facility will require approximately eight years after the final decision to go ahead, and forecasting the demand for electricity that far in advance has now become quite difficult. Initial estimates of the date for bringing the plant on-line varied from 1991 to 2000.

To help solve this technology choice problem, BG&E participated as a case study utility in the development of EPRI's technology choice model, with Woodward-Clyde Consultants as principal contractor. The motivation for using this sort of analysis was fourfold: to gain insight into the consequences of various decisions, to facilitate discussion within the company and with interested parties outside, to provide a convenient way to calculate the answers to "what if" questions, and to provide a rationale for the ultimate decision so that its responsiveness to critical issues could be accounted for responsibly. These issues included the cost of electricity, environmental impacts, public attitudes, health and safety, and technologic feasibility.

Poindexter describes the process this way: "First we participated in a background meeting so we would know what the plan was. Then they [the contractors] interviewed each decision maker separately so we wouldn't influence each other. In my interview, they first began to ferret out what I thought was important and then to ask in what directions I would be willing to compromise." The questions were tough. "They asked what importance I attached to the corporate bottom line and how would I trade that off against serving the customer. They also wanted to know how I felt about reliability and was that more important than earnings, and so forth."

Out of this grueling process began to emerge a clearer picture of the decision, Poindexter says. "If you have the various disciplines participating, you begin to break the problem down and see where the agreement is and where the disagreement is. You see each other's perspectives better. Ultimately, the top decision maker must be able to weigh all that and reflect on what's most important in his mind."

As expected, no clear-cut choice emerged from the BG&E analysis, but it did provide considerable insight into the problem. Under a set of base case assumptions (ranging from the discount rate to the heat rate), a conventional coal-fired facility with scrubbers, designed for a 1994 service date, appeared to be the best option. However, if the Texaco gasification process does turn out to be technologically feasible for a 1996 service date, then the analysis suggested this alternative would be best. If base case assumptions are shifted to indicate an increased probability that the Texaco process will indeed be available when it is needed, then waiting until 1988 to make the final choice begins to look increasingly attractive.

BG&E has not yet made its decision about the new plant, but it is bringing the technology choice model in-house to monitor how new information will affect the preferred alternative and to gain insight into the best time to act.

Three other utility applications have also been made of this technology choice methodology. The original development was with Utah Power & Light Co. on the choice between a coal-fired and a nuclear unit for its system expansion. Puget Sound Power & Light Co. used it to evaluate a decision concerning sites for a proposed nuclear plant. And Georgia Power Co. used the model to evaluate alternative sites for a planned pumped-hydro facility. René Malès, director of the Energy Analysis and Environment Division, says, "It is now hoped that other individual utilities, with the help of the reports on these applications and possibly with assistance from a knowledgeable contractor, may apply this technique to their own most important issues."

R&D strategy

Decision analysis has also been used successfully inside EPRI to help plan R&D strategy. The outcome of research is inherently uncertain, and determining which projects should receive highest priority requires consideration of many subjective factors. Often, charting an optimal course for R&D investment takes the form of a portfolio problem—one in which a decision must be made whether to concentrate development money on one promising line of research or to fund several alternatives. The advantage of the first strategy is that the most attractive course can be pursued more quickly; but if it fails, work on the alternatives would have to begin from scratch. The second strategy has less chance of failing completely, but hedging is expensive, and money put into the less-attractive alternatives may never be recovered.

The value of this use of decision analysis can best be seen in an example that was used to illustrate the technique: whether the time has come to freeze the design of a commercial atmospheric fluidized-bed combustion (AFBC) system. Two designs are available, either of which might eventually provide utilities with a cheaper way to meet stringent environmental standards, while accepting fuels of widely different quality. A standard-bed design has been incorporated into the 20-MW AFBC pilot plant at TVA's Shawnee station in Paducah, Kentucky, and the analysis assumed that a decision on whether to go ahead with a demonstration plant would be made in 1984. A circulating-bed design might offer higher combustion efficiency and lower consumption of limestone, but the earliest it could be ready for large-scale demonstration was assumed to be in 1986.

The analysis addressed two critical questions: Should a pilot plant also be built for the circulating-bed design? And, if so, under what circumstances should both designs move on to the demonstration phase of development? As very often happens, the insights provided were almost as interesting as the actual results.

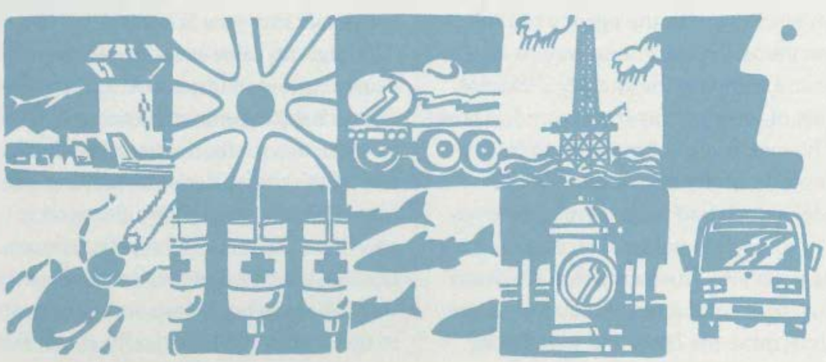
Applied Decision Analysis, Inc. (ADA), conducted the analysis. First, the problem was structured so as to express technical achievements from the pilot and demonstration plants in terms that are commonly used by utilities (e.g., capital cost, fuel flexibility). Next, a decision tree was prepared, incorporating expert assessments of the probabilities that each design would have optimistic pilot plant achievements and eventually meet demonstration plant goals—meaning that the technology met the positive goals for performance and cost.

"Decision analysis provided a forum for the fluidized-combustion staff to think about where we were going—reviewing all aspects of the technology development and seeing what the important factors were," explains Charles R. McGowin, technical manager for analysis in the Coal Combustion Systems Division. "We chose the problem as an example that would lend itself to this type of analysis. The biggest benefit was participating in the study, rather than making a final decision based on the results."

The results of analysis were dramatic. The only circumstances under which a pilot plant for the circulating-bed design should not be built would be if the likelihood of success was more than 90% for the standard-bed pilot plant and less than 10% for the circulating-bed plant. In fact, the EPRI technical staff estimates that the chances of an optimistic outcome for each pilot plant is roughly one in four. Similarly, when the effects of meeting demonstration plant goals are

Applications of Decision Analysis

- Structuring Corporate Objectives
- Location of Mexico City Airport
- Solar Electric Plant Siting
- Frozen Blood Policy
- Transporting Hazardous Waste
- School Integration Plan
- North Sea Oil Discharge Standards
- Technology Choice
- Treatment for Cleft Lip and Palate
- Loan Application Acceptance
- Rescue Missions
- Salmon Management
- Computer System Evaluation
- Blood Bank Inventory Control
- Selecting a Profession
- CO National Ambient Air Quality
- Reduction in Staff Personnel
- Nuclear Facility Siting
- Forest Pest Control
- Evaluating Energy Policy
- Fire Department Response
- Examining Foreign Policy
- Index for Severity of Physical Trauma
- Evaluating Pumped-Storage Sites
- Personal Investment Strategy
- Underground vs Aboveground Nuclear Plants
- Street Lighting Programs
- Modeling Adversary Preferences
- Evaluating Material Control Programs
- Developing Natural Resources



calculated, by far the largest range of possible outcomes indicates that both designs should be demonstrated.

The ratio of benefits to costs for going ahead with the circulating-bed plant was found to be about 8 to 1. Further, the analysis showed how much certain initial assumptions would have to vary in order to change the results for key decisions. The answer provided was that benefits would have to be cut to 11% of assumed values before they would just equal the expected costs. (Such conclusions, those that remain unchanged even when initial assumptions are varied substantially, are called robust.)

Peter Morris, a principal with ADA, concludes, "Decision analysis helps capture the value of surprises. In the R&D context, it can help you figure out the decision you really want to make, based on what you think the outcomes are likely to be."

A framework for policy decisions

Probably the most complex use of decision analysis is to provide a means for resolving sensitive policy disputes by integrating scientific information from diverse fields with public concerns. One particularly important policy area where such a resolution is badly needed is acid deposition.

As the debate on acid rain has intensified, the need for an integrating framework to balance potential environmental effects with the costs of emissions control has grown, according to Richard Richels, technical manager of decision methods and analysis, Economic Environmental Integration Staff. "The choice involves the careful balancing of very different types of risk. Acting now to reduce emissions carries the risk that large expenditures will be made with little or no beneficial effect, while waiting carries the risk that significant ecological damage will be incurred that could have been prevented by prompt action. Unfortunately, resolution of crucial uncertainties may not occur for 5–10 years, or longer. Until that time it will not be possible to predict accurately how changes in emissions will affect the extent of ecological damage from acid deposition. What we have tried to do is to provide a unified framework for reaching the best decision on the basis of information available at a given point in time."

Constructing such a framework must begin by explicitly laying out the areas of uncertainty. Although there is a presumed relationship between emissions from a power plant at one location and ecological damage caused by acid deposition at another location hundreds of miles downwind, each step of the process is now uncertain. Such uncertainties can be taken into account by carefully defining possible outcomes for each step, then having experts from different fields assess probabilities for the various alternatives. Such an analysis framework has now been constructed under EPRI sponsorship by Decision Focus, Inc., and implemented as a computer code called ADEPT (acid deposition decision tree).

One of the first important applications of the ADEPT model has been to analyze the acid deposition problem in Minnesota. There the state legislature has instructed the Minnesota Pollution Control Agency to impose acceptable limits on such deposition. Unfortunately, the effect of even stringent emission controls on acid deposition remains quite uncertain, and potential beneficiaries of reduced emissions are not necessarily the same people who must bear the cost. The Air Quality Task Force of the Minnesota-Wisconsin Power Suppliers Group has been working with the agency to find some mutually acceptable way to analyze and compare the sharply different points of view on this controversial issue.

The task force volunteered to be a case study utility to test the ADEPT model, which had been developed originally to analyze national strategies, on a state problem. The contractor, Decision Focus, Inc., conducted two analyses: one to determine the costs and benefits of regulatory changes within Minnesota, and one in which all states in the region adopted similar regulations. Using state models of lake alkalinity and a worst-case scenario, the contractor identified about 150,000 acres of lakes in the northeastern corner of Minnesota that were most sensitive to potential damage.

Next, expert opinion was sought on the environmental effect of sulfur dioxide reductions consistent with provisions of the Mitchell-Stafford bill, now before Congress. If adopted, these provisions would effectively require reducing sulfur dioxide emissions from coal-fired plants in the eastern United States by an average of 50%. An effort was also made to express the impact of possible environmental damage in monetary terms. Such values were based on estimates of how the Minnesota public views the recreational importance of the lakes in question.

By providing a framework for discussing total costs, including both emission control and possible environmental damage, the decision analysis model provided some important insights. The most robust of these was that the strategy incurring the least total cost for either local or regional emission control would involve postponing any new controls so that more research could be done on acid deposition. In other words, the risk of substantial environmental damage within a decade appears to be much less than the benefits that are likely to result from new knowledge.

Directions for the future

The use of decision analysis in the electric power industry is just beginning. Although its value has already been demonstrated in important specific cases, changing circumstances are likely to make this methodology a regular feature of the utility decision-making process. The more complex a decision is and the more it involves critical uncertainties, the more useful decision analysis is likely to be. By encouraging people to think more systematically, it can facilitate the solution of problems that involve a sequence of interrelated decisions too complicated for the mind to grasp intuitively.

"Decision analysis is not only more rational and comprehensive but also practically more powerful and useful than the more common approaches to cost-benefit analysis," asserts William B. Harrison, senior vice president of Southern Company Services, Inc. In commenting on the ADEPT model: "I believe comparison with other methodologies makes it clear that these techniques may be more usefully applied to many of the complex problems faced by our industry."

Decision analysis may also open an important new communications link between utilities and the communities they serve. Many of the public policy debates swirling around the electric power industry have been sidetracked into discussions concerning technical details that may ultimately prove irrelevant. As an alternative, decision analysis may help focus discussion on community values that have the utmost importance. "Values represent the side of the problem on which the public really has something to say," concludes Keeney. "In this case they have very valid input—what they want."

Individual utilities may find the powerful techniques of decision analysis applicable for helping to solve a wide range of daily business problems. "In my company we have found it very useful," says James McCloy, a corporate planner with Georgia Power Co. "A couple of years ago, when we reviewed our capital additions program, decision analysis allowed us to look at a wide variety of options, including joint ventures. As a result, the analysis led us to marketing that new capacity in a nontraditional way."

Such uses may become even more important if utilities begin to diversify into new and unfamiliar lines of business. "Decision analysis allows you to evaluate more options," McCloy continues. "It forces your logic onto the table so everybody can see it. And if there is a problem with your logic, it jumps right out and grabs you. No question about it—we find the technique very, very useful."

Further reading

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This article was written by John Douglas, science writer. Technical background information was provided by Richard Richels, Energy Analysis and Environment Division.

Particulates: Caught at

the Filter Line

The dustcake captured on the inside of a fabric filter is the key to baghouse performance and the focus of recent research. Utility interest and confidence in this technology are growing rapidly.

Electric utilities have made a number of important advances in recent years to improve the efficiency, reliability, and economics of environmental control systems on coal-fired generating plants. Some of the most significant of these have been in the collection of particulate matter by using fabric filters, or baghouses.

Along with nitrogen oxides (NO_x) and sulfur dioxide (SO_2), particulate matter—small particles of fly ash produced when coal is burned—is a product of coal combustion that must be controlled at the source. Ten years ago one technology was used predominantly by utilities for particulate control: electrostatic precipitation. In recent years, however, baghouses have been shown in both pilot- and full-scale demonstrations to perform as well as precipitators in terms of efficiency, reliability, and economics. Moreover, they offer the option of combining SO_2 and particulate collection, thereby reducing the need for separate SO_2 removal equipment, which can account for up to 25% of total plant cost.

In 1973 the first full-scale baghouse was installed by Pennsylvania Power & Light Co. at its Sunbury station. Today, utilities are ordering as many baghouses as precipitators, with 116 baghouse units representing 20,921 MW of capacity in operation, in design, or under construction. Reflecting growing confidence in the technology, unit sizes are increasing as well: up from 100 MW or so a few years ago to 500–800 MW today. Most of these units are being installed on plants fueled by low-sulfur western coal (less than 2% sulfur). But interest is growing in installing them in high-sulfur eastern coal applications as well (2–5% sulfur).

The distinction between high- and low-sulfur coal has been important in the emergence of baghouses. Utilities in the United States burn approximately the same quantities of each, but in the combustion process high-sulfur coal produces more SO_2 than low-sulfur coal. Consequently, with the establishment of more-stringent SO_2 control regulations in the early 1970s, utilities began to opt more and more for low-sulfur coal to reduce SO_2 concerns. However, precipitators (then the dominant particulate collector) did not prove as effective in capturing particulate matter from these coals as from high-sulfur coals. As a result, attention moved to baghouses as an alternative.

In application to date on both low- and high-sulfur coals, baghouses have proved capable of routinely capturing 99.9% of particulate matter in flue gas—well within EPA New Source Performance Standards. Also, they produce a clear stack (i.e., no visible emissions when filtered flue gas is released into the environment).

"Baghouses have clearly established that with routine maintenance they can consistently maintain high collection efficiencies and a clear stack," says Robert Carr, manager of the Air Quality Control Program in EPRI's Coal Combustion Systems Division. "Further, they offer the unique option of combined particulate-SO_2 control. This isn't to say there aren't areas in which we can improve the technology. But it does say that in a very short period of time—a decade—baghouse technology has gone from ground zero to the point where it is now a viable and economic environmental control option for utilities."

Given the high level of collection efficiency inherent with baghouses, research has focused instead on improving unit durability, reliability, and economics and on expanding capabilities for broader and more versatile application. In the first area, emphasis is being placed primarily on reducing the amount of energy required to pull flue gas through the units, quantified in terms of pressure drop, and on reducing unit size, quantified in terms of the amount of flue gas to be filtered per unit of bag cloth area (air-to-cloth ratio). In the second area, use of baghouses on boilers burning high-sulfur coals and combined SO_2-particulate collection are receiving the most attention.

Baghouse operation

Located downstream of utility boilers, baghouses receive flue gas produced in the coal combustion process through large ducts. These ducts route the gas to one of a number of separate baghouse compartments, where it is directed upward through a cell plate—a sheet of perforated metal with collars, or thimbles, protruding from each cell—and into the tube-shaped bag, or fabric filter. These bags, which are generally about 35 ft (11 m) long and 1 ft (0.3 m) in diameter, are suspended from above and attached to each cell at the thimble.

In the United States, utilities use inside-out collection, where flue gas is routed into the bag at the bottom and then passed through the fabric to the outside along the bag's height, trapping and depositing particulate matter on the inside surface of the bag. In this filtering process, a clean bag is not the most efficient collector. Rather, it is the collected particulate matter on the inside of the bag (the dustcake, or filter cake) that acts as the filtering medium.

In baghouse operation, pressure drop is critical because higher pressure drops mean that more energy is required to pull flue gas through the system. Measured in inches of water, a pressure drop of 4–6 in (10–15 cm) is typically desired and sufficient to move the flue gas economically through the system. Operation at higher pressure drops can become expensive, however, inasmuch as the energy cost for each inch of pressure drop is approximately $100,000 a year for a 1000-MW plant. Also, pressure drops that exceed the design limit of the fans can mean that station boilers must operate at less than full load, a very costly situation.

Air-to-cloth ratios represent the most important parameter of baghouse design because they determine the size and thereby the capital cost of units. This ratio is calculated by dividing the volume flow of flue gas received by a baghouse by the total area of the filtering cloth, and it typically varies from about 1.6 to 3.4—a nominal ratio being 2. Higher air-to-cloth ratios mean less fabric, thereby less structure and capital cost. But with smaller amounts of cloth, pressure drop can become more of a problem, forcing energy costs up, and more-frequent bag cleaning may be required, meaning increased compartment downtime and the potential for reliability problems.

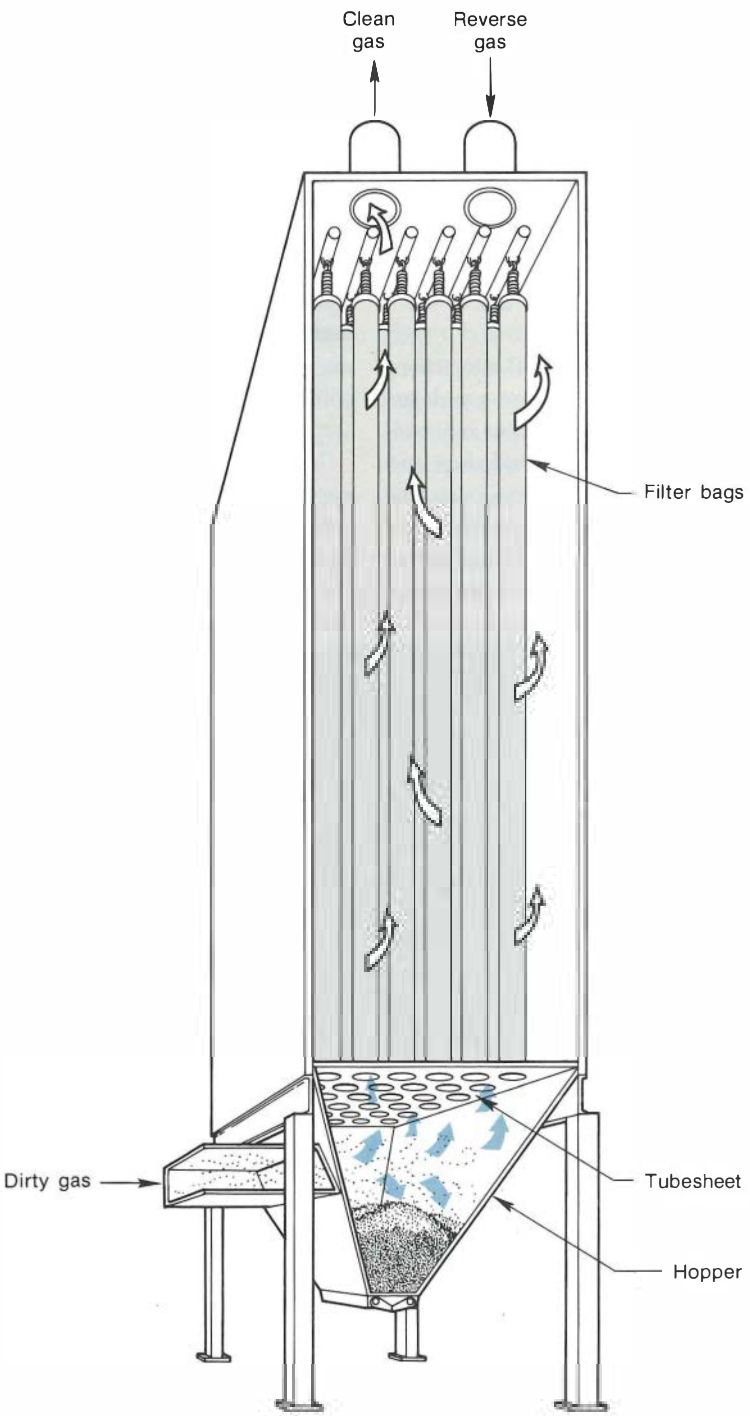
"By and large," explains Carr, "if you look at the problems you could have with a baghouse, the biggest problem has been in achieving and maintaining low pressure drops. A number of operating parameters influence pressure drop, and we are looking closely at each of these in our research. Most important in this regard are the residual dustcakes that remain on bags after cleaning, the bag-cleaning process itself, bag fabrics, and flue gas flow distribution."

EPRI's research in these areas is conducted under a contract with Southern Research Institute. The work includes laboratory studies and full-scale unit evaluations at various sites, as well as pilot plant operation at two locations. The oldest pilot unit is the Arapahoe Test Facility, operated in cooperation with the Public Service Co. of Colorado at its Arapahoe station in Denver. This unit, commissioned in April 1979, filters fly ash from a boiler burning low-sulfur, subbituminous coal. In July 1982, in a cooperative program with Gulf Power Co. and Southern Co. Services, Inc., EPRI also began operating a pilot unit on a boiler burning high-sulfur coal at Gulf Power's Scholz station near Sneads, Florida. Both sites have 10-MW baghouses capable of filtering up to 35,000 actual ft^3/min (16.5 m^3/s) of flue gas. Arapahoe also includes smaller 1- and 2.5-MW baghouses.

Residual dustcakes

Research recently undertaken by EPRI to better understand the role and dynamics of residual dustcakes—that portion of the dustcake left on bags after cleaning—has revealed an interesting characteristic not previously observed or reported: the unique nature and configu-

Baghouse technology is essentially modular. Shown is one baghouse compartment, illustrating hopper, tubesheet, and bag arrangement. Each compartment can contain several hundred bags up to 35 ft (11 m) tall and 12 in. (305 mm) in diameter. A commercial-size baghouse can have from 8 to 32 such compartments.



ration of the filter cake on the filter. It is becoming clear that baghouse collection efficiencies and pressure drops are not determined by bag fabric, but rather by the nature of the residual dustcake on the fabric.

Because of the importance of this residual dustcake, experimental procedures have been developed to characterize the physical, chemical, and electrical properties of collected ash in order to investigate the mechanics of cake formation and adhesion. These studies have been performed at Arapahoe and at several full-scale utility baghouses. The ultimate goal is to develop sufficient understanding to allow prediction and optimization of pressure drop and collection efficiencies.

As part of this work, a technique has been developed to encapsulate fabric and dust samples in a low-viscosity epoxy for detailed examination. These samples are then cut and polished for viewing in cross section or coated with a conducting material for viewing under a scanning electron microscope.

The majority of dustcake data taken to date are from baghouses cleaned by the reverse-gas method, the most widely used cleaning option in U.S. utility settings today. With reverse-gas cleaning, a gentle pulse of filtered gas is directed back into the baghouse compartment and through the bags, causing them to partially collapse inward and dislodge accumulated dust. Studies show that residual dustcakes on bags cleaned by reverse gas are characterized by large nodular formations, crevices or fissures, and relatively thin cake layers along lines where the bags fold during cleaning. They also show that residual dustcakes on these bags typically weigh up to 60–100 lb (27–45 kg)—ten times as much as the amount of dust collected over a single filtering cycle. These are significant findings in terms of better understanding both pressure drop and the reasons for premature bag failure in reverse-gas-cleaned units.

In terms of pressure drop, the presence

of a thick, impermeable, residual dustcake means that only a portion of total bag fabric area is actually being effectively used in the filtering process, perhaps only as much as 40%. As a result, as flue gas attempts to pass through the bag it must follow a tortuous route to seek out cracks, voids, and folds in the dustcake. As it finds these paths, they subsequently plug up with collected particulate matter and passage becomes even more difficult. The net result is higher and higher resistance to gas flow and a consequently greater and greater demand for energy to pull the gas through the system (i.e., higher pressure drop). In addition, because gas flow is being forced to flow through restricted regions, the effective air-to-cloth ratio of baghouses becomes higher than the design value.

Observations that dustcakes on bags build to become tenacious structures also support the view that pressure drop is a dynamic rather than static parameter. This thinking is reinforced by data that show pressure drop to be characterized by two distinct patterns of behavior. The first occurs after startup as the filter cake becomes established on new bags; this pattern may extend for several months. The second occurs after a substantial, perhaps permanent, residual dustcake is established on the bags. The difference is that during the first period, pressure drop increases rapidly in the initial few months and then much more slowly as it approaches what appears to be a state of near equilibrium. Once the residual dustcake is formed, however, there is quite a bit of day-to-day variation in pressure drop over time, accompanied by a very slow, persistent increase.

In terms of premature bag failure, it is now theorized that heavy residual dustcakes contribute significantly to bags going slack and then failing in their lower extremities. This confirms survey results of full-scale units, which show bag failure largely limited to this region.

Dustcake studies at the Scholz pilot plant on reverse-gas-cleaned bags filtering fly ash from high-sulfur coal are similar to those at Arapahoe. However, the structure of the dustcakes at Scholz is somewhat different, and the weights of residual dustcakes have been observed to be somewhat larger than those at Arapahoe.

"We're putting a lot of effort into analyses of dustcakes," reports Carr, "and we now understand a lot better than we used to how important the fabric-dustcake interface really is. However, we still don't know the most effective method of cleaning to remove those residual dustcakes or how much residual is appropriate."

Bag cleaning

EPRI's studies of residual dustcakes clearly indicate that the reverse-gas cleaning process can be improved to more effectively remove accumulated dust and to keep pressure drops down. To accomplish this, three approaches are being investigated: changes in bag-cleaning frequency, changes in the volume of reverse gas used in cleaning, and use of sonic energy enhancement (i.e., horns). Of the three, sonic enhancement appears most promising.

At Arapahoe, using horns has proved extremely successful, with the sonic blast dislodging virtually the whole of residual dustcakes and reducing pressure drop by up to 50%. Six commercially available horns with different fundamental frequencies are being evaluated, as well as a generic horn developed for EPRI and capable of operation at a continuum of fundamental frequencies and energy outputs. In addition to horn frequencies, horn location and the timing and duration of horn soundings are being studied. Separate sonic testing by Public Service Co. of Colorado on full-scale reverse-gas-cleaned baghouse compartments at Arapahoe has also resulted in dramatic reductions in residual dustcakes, decreasing pressure drop in those compartments about 40%. As a result, the utility has purchased and installed horns in all baghouse compartments serving one boiler.

Sonic horns have also been preliminarily tested by EPRI at the Scholz pilot plant. Again, however, results at this site have been somewhat different from those of baghouses filtering low-sulfur coal. Specifically, while substantial pressure drop reductions are seen after sonic horns are activated, only about one-third of residual dustcakes are actually being removed.

Overall, according to Carr, a number of critical questions remain to be resolved before sonic enhancement can be considered as proved effective. These include determination of optimal sonic energy density requirements and acoustic frequencies, optimization of cleaning cycles and horn location, and assessment of the technology's long-term effectiveness with different types of fly ash. Each of these issues is now being addressed.

In addition to efforts to improve the reverse-gas cleaning process, utility interest in alternative cleaning technologies is also increasing. Shake/deflate cleaning looks especially promising. This method involves manipulating bags from the top so as to send a traveling wave down their length while they are being deflated.

Interest in shake/deflate cleaning centers on the fact that baghouses using this technology tend to have residual dust cakes on the order of 20 lb (9 kg) (versus 60–100 lb [27–45 kg] with reverse gas) and pressure drops about half those of reverse-gas-cleaned units. In the past, utilities have shied away from shake/deflate cleaning because of concern it would accelerate bag wear over time. Today, however, it appears this need not necessarily be a concern inasmuch as shaker mechanisms have been improved and the unit's lower system pressure drops will mean cleaning is required less frequently.

EPRI's activities to characterize and optimize shake/deflate cleaning are being increased substantially in line with the growing awareness of the advantages the technology could provide. This work will involve both pilot- and full-scale unit investigation. In application to date on two 360-MW boilers at Southwestern

Public Service Co.'s Harrington station, shake/deflate-cleaned baghouses have performed very well.

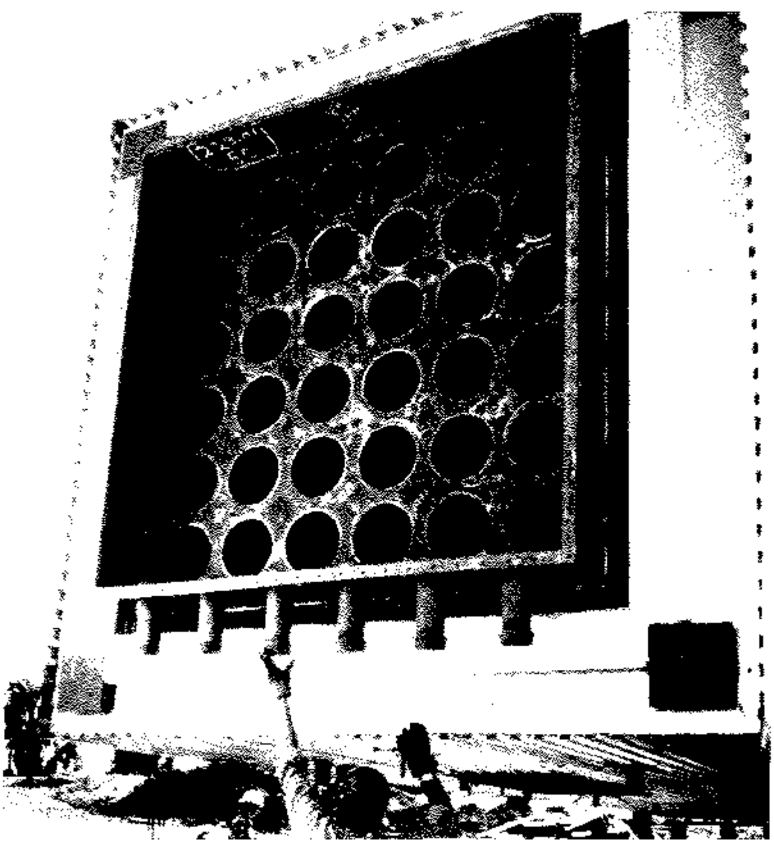
"In our experience shake/deflate cleaning can be done on fiber glass bags without undue failure," says Richard Chambers, supervisory engineer at Southwestern Public Service. "With the proper choice of fabric and an optimized cleaning cycle, the fabric filters at Harrington station are expected to give a 4.5–5-yr bag life. Bag replacement economics indicate that reverse-air bags will have to stay in service about twice as long as shake/deflate bags to be economically competitive. Further, shaker maintenance on a properly designed and well-maintained system is not the nightmare that some thought it would be."

Fabrics and flow distribution

The most critical element in fabric filter technology is the bag itself. Because the bag acts principally as a matrix on which the dustcake is formed and not as the primary filtering mechanism, it is chosen for its temperature and chemical resistance, its mechanical stability, and its ability to be woven to collect the desired dustcake and then permit that cake to be easily removed in cleaning.

Although various fabrics are adaptable for this application, approximately 90% of all U.S. utility baghouses use fiberglass. Fiberglass has the ability to function at a higher temperature than the alternatives, it has good resistance to chemical attack when appropriately finished, and it is inexpensive in comparison with other high-temperature fabrics.

For low-temperature applications (280°F [138°C] and below), or where gas cooling may be required upstream of the baghouse, acrylic is a potentially attractive alternative to fiberglass at approximately one-half the cost. However, acrylic bags are typically smaller than fiberglass bags, raising questions about maintenance and replacement requirements. Use of acrylics also raises concerns about dimensional stability and subsequent loss of bag tension, particularly at elevated temperatures in larger sizes. In application to date in Australia, acrylic bags have demonstrated good performance.



Today, bag fabric research is being focused on two general goals: to improve performance and economics and to promulgate standards and quality control guidelines.

Investigation to improve fabric performance and economics is directed toward enhancing bag permeability, cleanability, and durability, and it involves monitoring pressure drop, particulate matter penetration, and residual dustcake weight and release characteristics. Different weaves and finishes for fiberglass fabric are also being investigated, as are alternative materials, such as ryton and felted glass, as well as acrylics.

In terms of bag standardization, EPRI is now in the process of bringing together a utility advisory committee to develop standards and quality control guidelines for bag fabric, design, weave, finish (when applicable), and fabrication. In addition, a series of meetings are being planned with bag fabricators and processors to share the results of EPRI-sponsored research and survey data and to solicit vendor participation in the standardization development effort. Today, no product standard exists for the utility industry.

Dust flow distribution to and through baghouses is a separate area of unit operation also receiving research attention. In this effort, a great deal of data are now available to suggest that pressure drop losses from poor dust flow distribution can be easily avoided. In system ductwork leading to baghouses, for example, flue gas moves at rates of up to 60 ft/s (18 m/s). Without proper fluid mechanic design, eddies and flow separation can result, increasing pressure drop and segregating dust particles by size among compartments, influencing the character of filter cakes in those regions. Flow distribution can also be a problem inside baghouse compartments, but again, this can be resolved with proper design.

High-sulfur coal applications

The vast majority of electric utilities in the eastern and midwestern United States burn high-sulfur eastern coal in their coal-fired generating plants. Electrostatic precipitators generally work well in collecting particulate matter in these applications, but they do not offer the option of combined particulate-SO_2 control; precipitators are not as efficient as baghouses in collecting fine-particulate matter and may have difficulty meeting emission standards if new, more-stringent regulations are put into effect.

For these reasons, utility interest in baghouses for high-sulfur coal applications has increased appreciably in recent years. However, high-sulfur coals present new challenges to optimal baghouse operation. For example, they produce a different filter cake on the bag, one with unknown cleaning and filter cake release characteristics. Also, they produce higher SO_2 and SO_3 flue gas concentrations than low-sulfur coals, and subsequently have higher acid dew points—levels at which acid in the flue gas will condense and form droplets that can corrode metal and perhaps damage bags.

Filtering fly ash from 2.6–3.2% sulfur coals has been impressive at the Scholz test facility, indicating that utilities can consider installing commercial-scale baghouses in high-sulfur applications. Removal efficiencies have been greater than 99.9%, average pressure drop has been approximately 4 in (10 cm), and outlet opacity on the unit is extremely low—only 0.03% (2–4% opacity represents the threshold for a clear stack).

The pilot baghouse at Scholz operates off slip streams from a 40-MW pulverized-coal-fired boiler. During testing, this boiler is deliberately operated in a cycling mode to observe below–dew point operation and variations in temperature and ash concentration in baghouse compartments. Even under these off-design conditions, however, the baghouse has exhibited better than 99% availability. It has also undergone several shutdown-startup sequences, all without unit preheating to avoid acid dew points or the precoating of bags to protect against acid attack; the baghouse continues to operate at a relatively low pressure drop with no deleterious effects. Future tests at Scholz will include pilot plant operation in different cleaning modes and at higher air-to-cloth ratios. Training sessions for EPRI member utilities, including hands-on operation of the unit, are being offered at this site. The participants may spend a few days or up to two weeks there, depending on interest. "The high-sulfur unit operates as well as a low-sulfur baghouse," says Richard McRanie, manager of particulate control and combustion research for Southern Co. Services. "We have had none of the anticipated problems in filtering fly ash from high-sulfur coals: corrosion, bag deterioration, or bag blinding. In fact, our major challenge at this point is to figure out why it's working so well."

Combined SO_2-particulate collection

Two technologies for combined SO_2-particulate collection are receiving extensive utility attention: spray drying, which is commercially available and in limited use by utilities, and injection of all-dry sorbents, a technology now emerging for commercial application. Both offer significant cost-saving potential as replacements for wet-scrubbing equipment widely used in the utility industry for SO_2 control.

The most promising option is all-dry sorbent injection. Here a sodium-based reagent is pulverized and fed into the flue gas stream ahead of the baghouse and downstream of the air heater. This reagent collects on the bags as part of the dustcake, removing SO_2 as it attempts to pass through. Nahcolite reagent has received most attention in this application, but economics of mining nahcolite may hinder its availability. As a result, recent attention has focused on trona, a commercially available alternative that has shown promising test results.

The technical feasibility of dry injection in utility applications has been demonstrated by EPRI and Public Service Co. of Colorado on its 22-MW Cameo Unit 1. This testing confirmed the capability of 70% SO_2 removal (the present EPA New Source Performance Standard for low-sulfur coal) with the injection of nahcolite and trona without detrimental impact on baghouse operation or performance. Significantly, results with trona were for material as received from the ground, and trona suppliers now believe that beneficiation to remove impurities will greatly improve the reagent's SO_2 collection efficiency. Better methods of injection will also appreciably improve trona's performance in this application. Given trona's promise in combined SO_2-particulate collection, suppliers are now undertaking R&D on their own to improve the characteristics of their product for the application.

"If one were to look at the possibility of more-stringent future SO_2 legislation for existing units, all-dry sorbent injection using either nahcolite or trona is a viable alternative," asserts George Green, manager of government licensing and planning for Public Service. "All the studies we have done are site-specific, but I think that when you consider the merits of the process, how simple and reliable it is, you can't help but like it." Reflecting this attitude, Public Service recently committed to all-dry injection for SO_2 control on a new 500-MW unit scheduled to begin service in 1989.

In contrast to all-dry injection, spray dryer operation involves spraying flue gas with an alkaline reagent in a slurry. In this process the SO_2 is converted into a dry, solid product that can be filtered out with particulate matter in the baghouse. To build a data base on this technology, EPRI began operating a 2.5-MW spray dryer pilot plant at Arapahoe in February 1982. Approximately 60% of this work is now complete, with test series having been run that used both once-through lime and recycled-lime reagents.

Results show that recycled lime is the preferred mode of spray dryer operation, with system collection efficiencies achieved at over 90%, four-fifths attributable to the spray dryer and one-fifth attributable to the baghouse. Successful operation in the once-through lime mode appears to require careful optimization. Some corrosion problems thought to be related to insufficient insulation in the baghouse have been experienced, but these should be correctable with proper design.

To assess the economics of combined SO_2 and particulate control, EPRI recently funded a study that compared commercial-size nahcolite and trona all-dry injection systems with commercially available spray dryer systems. The analysis was performed for a hypothetical power plant located in Kenosha, Wisconsin, which consisted of two 500-MW units burning 0.5% low-sulfur western coal.

Results showed capital costs of trona and nahcolite dry injection systems at about $25/kW, compared with $115/kW for spray drying. On a levelized cost basis, trona injection was least expensive, followed by nahcolite injection and spray drying. However, these economics were found to be highly sensitive to the delivered price of the sorbent, sulfur content of the coal, and SO_2 removal requirement. Cost for waste disposal and the size of the generating plant were found to be important but less significant.

Looking ahead

According to Carr, the time required to achieve what appears to be stable operation after an operating change in a baghouse is quite long, and the results of short-term tests must be carefully interpreted. However, investigations to date have generally recognized this, and the conclusion can be confidently drawn that baghouses do represent an efficient, reliable, and economic alternative for particulate collection in a wide range of settings. "Baghouse efficiencies started out high and have stayed high," he comments, "so we haven't had to be too concerned about that. Instead, we've concentrated our attention on reliability, durability, economic operation, and expanded application. By and large, we've been quite successful. But a few poorly performing units do exist, and we need to better understand why. We know that maintenance procedures have to be improved, for example, and in one instance in Texas we have found a coal fly ash that is very difficult to filter with woven fiberglass. There, special research is required."

Carr also says that there are a number of potentially exciting advanced options for baghouse design and operation. One of these is electrostatic augmentation of fabric filters, a technology that combines aspects of the electrostatic precipitation process with baghouses in an effort to reduce baghouse size and pressure drop. EPRI and EPA are devoting major research emphasis to this technology and have seen some very promising results in pilot-scale testing. In this work, results have shown the potential for significantly reducing pressure drop—up to 50% in some instances. Further pilot work will focus on optimizing this aspect of the technology, as well as on scaling it up to commercial sizes.

Advanced options like electrostatic augmentation remain in the future, however. For the moment, the primary concern in Carr's mind is solving the problem of high-weight residual dustcakes in reverse-gas-cleaned baghouses. Reducing these dustcakes would reduce pressure drops and therefore operating costs, allowing for higher design air-to-cloth ratios and lower capital costs. Any increased cost of operation as a result of higher air-to-cloth ratios, he feels, would be more than offset by the capital cost savings realized. Also, reduced dustcakes would mean reduced need for bag cleaning, thereby reducing stress on bags and extending their service life. "Once we solve this dustcake problem," he says, "we will have taken a giant step toward optimizing the technology." ■

Further reading

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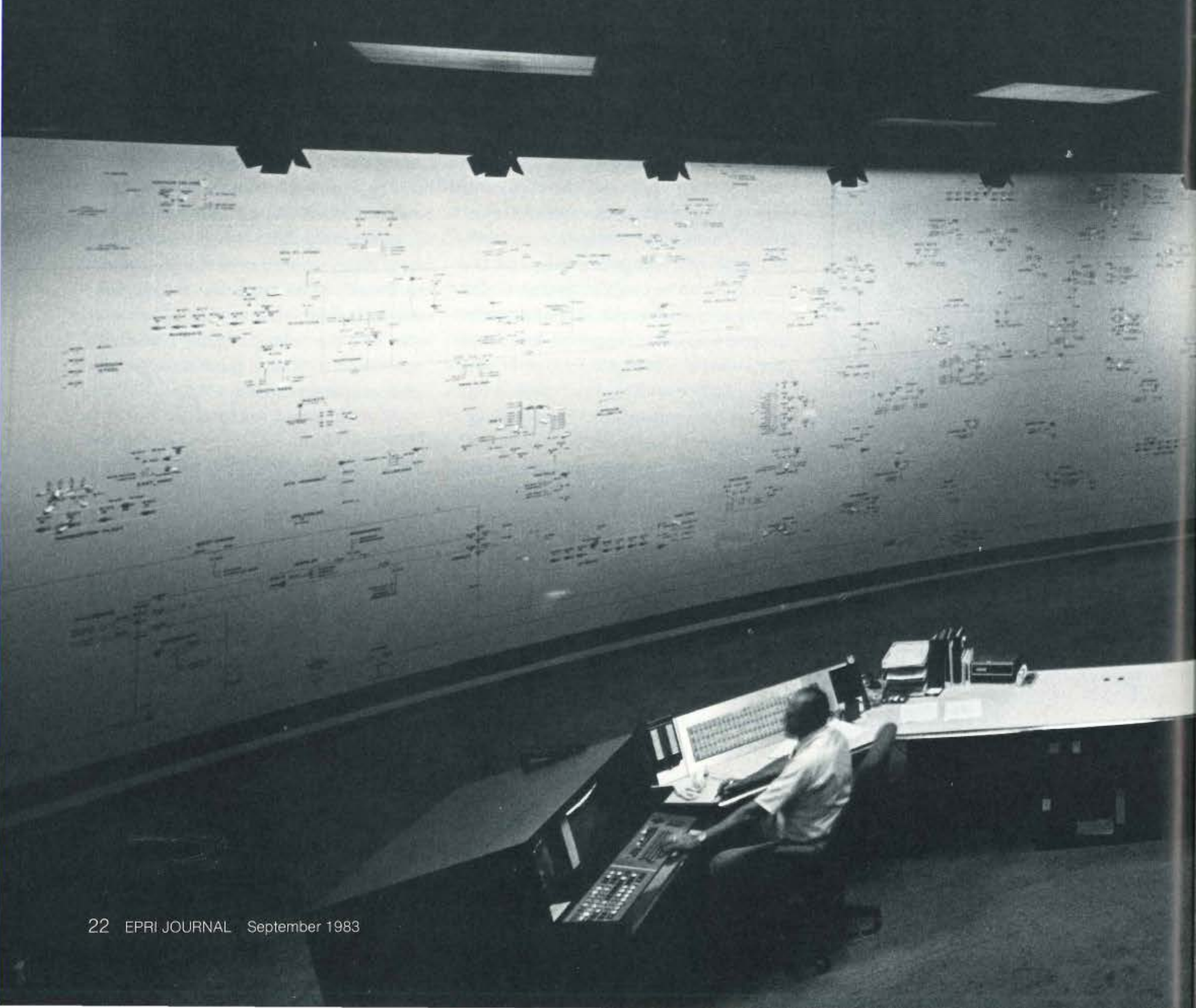
This article was written by William Nesbit, science writer. Technical background information was provided by Robert Carr, Coal Combustion Systems Division.

Nerve Center for Network Control

Dispatching to meet dynamic power demands is a highly complex and stressful operation. Research on human factors, operator training, and advanced computer systems will help the dispatcher manage the huge inflow of constantly changing information.



Modern electric power systems may be likened to human physiology: generating plants are the system's organs and muscles, converting fuel to energy for work; transmission lines form a kind of circulatory system, providing a path for the flow of energy from where it is produced to where it is needed. There is a third area where the functional similarity is striking. In the human body, it is the brain and central nervous system that monitors and regulates the work of subordinate elements. In the electric power system, this function is performed by computers and a complex communications and control network located in a power systems control center. Together, they are sometimes called an energy management system, or EMS.

About 120 independent power system control centers in the United States supply a typical daily peak demand of 350–400 GW. Because electricity, with few exceptions, cannot be stored in large amounts, the responsibility of monitoring and following demand is unceasing. Hundreds of system operators, assisted by on-line computers, work in shifts around the clock, seven days a week. Computers track the minute-by-minute fluctuations in demand and ensure that just enough power is produced to meet the demand with the most economic mix of fuels and generation technologies.

The North American power transmission network consists of two large interconnected systems. The eastern system extends to the Rocky Mountains and in-

cludes eastern and central Canada. The western system covers all areas west of the Rockies and the adjacent Canadian provinces. A critical responsibility of each system operator is to preserve the security of his respective portion of this vast interdependent network. Power system contingencies, such as those caused by lightning, tornadoes, and the like, could threaten system security and occur at any time with unpredictable severity. When contingencies occur, operators must restore the power system to a secure condition and prevent further contingencies from developing; otherwise, key facilities can become overloaded and damaged.

An important function in system operation that touches all of us in daily life is the maintenance of constant network frequency. The U.S. power system operates on a 60-Hz (cycles per second) frequency standard that affects the speed of all rotating electrical machinery; significant deviations from the standard over more than a few minutes could damage all sorts of equipment in many manufacturing and industrial processes.

Power system control, also known as power dispatch, is semiautomatic; sophisticated computers handle many of the monitoring and calculating chores. They automatically fine-tune generating output to follow demand and allocate the most economic mix of baseload, cycling, and peak generating units. The energy management systems process tremendous volumes of data that keep the system operator informed of the status of hundreds of generation, transmission, and distribution elements in the power network.

Research focus

Utility industry research to advance the fidelity and capabilities of computer models used in power system control is a major part of the work of the Power Systems Planning and Operations Program in EPRI's Electrical Systems Division. EPRI-developed models include programs for economic fuel allocation and use, as well as automatic generation control. But increasing attention is being focused on the system operators themselves. This elite corps of utility personnel is, in the final analysis, responsible for running the nation's power systems, using whatever equipment and computer assistance is available.

As with air traffic controllers, there is little margin for error on the part of power system operators, and the conditions under which they perform are sometimes less than ideal. Utilities are constantly seeking to improve the operators' knowledge of the system's status. The physical characteristics of the work environment may hamper critical decision making. The training by which operators are prepared to handle system contingencies requires constant improvement.

With the aim of helping operators more effectively avert system outages and near-misses and preserve system security, several EPRI projects focus on achieving a better understanding of the system operator's job and on the development of better tools and training. These include advanced systems for simulating power systems more realistically for training purposes, a detailed look at human factors design in control rooms, and new techniques for applying computers to augment the knowledge and experience of system operators. The importance of these research areas to improved system operations becomes apparent on further examination of the operator's job and the implications of utility industry trends.

The dispatch function

Information is the system operator's stock in trade, but the type of information needed for making decisions varies according to the time domain of immediate activity, as well as the status of the power system.

At the beginning of each shift, in what is called the predispatch domain, a system operator is occupied with short-term load forecasting, scheduling generation-unit output and reactive power levels, and planning power interchanges with neighboring utilities or operating pools, as well as maintenance activities that affect the availability of equipment.

In the dispatch domain, the operator monitors and controls the energy management system that adjusts generation capacity to meet demand and directs power interchanges and transmission line switching. Postdispatch activity consists of after-the-fact logging, accounting, and problem analysis of actions taken during dispatch. Results of the analyses are used to improve future operations. Such is the operator's normal work routine.

When normal operating conditions do not prevail because power transfer limits are exceeded or because of some weather-related disturbance, a power system is said to be in a degraded state. This can range in degree of seriousness from only a warning condition to a system collapse. The operator must maneuver the system back to normal, carefully moving from one of the degraded states (warning, alert, major emergency, or collapse) to a condition in which all customer requirements are met and the system is operating in a secure, economic mode.

Information processing

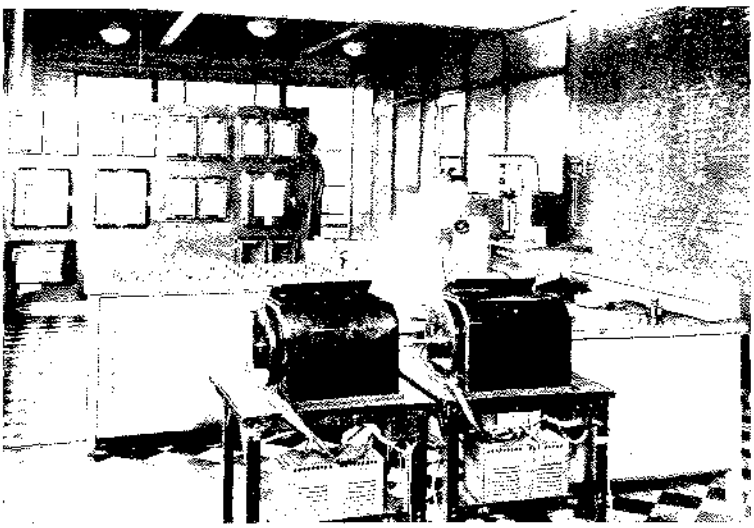
Organizing the presentation of information to the system operator can pose a major challenge, given the volume of data received by the control center's energy management system. Until the last decade or so, the best available means of doing this were banks of strip chart recorders and large system mapboards representing the utility network of generating plants, transmission corridors, switching equipment, and substations.

But as power systems grew more complex, the inherent limitations of fixed, physical information displays within a finite physical space became apparent. The mapboards, sometimes the size of an entire two-story control center wall, came to dominate control room design. As the mapboards became bigger and more crowded, they were harder to read and more vulnerable to misinterpretation.

An important recent development has

been the advent of video, or cathode ray tube (CRT), display systems tied directly to the energy management system. CRT one-line diagrams and system overviews are used both to convey information to the operator and to permit more effective operation of the system via a computer keyboard.

Time is the operator's most critical constraint, however, and it figures prominently in all aspects of information display and operator decision making. The time it takes for the millions of data points (readings of voltage or power flow) from thousands of plant and system sensors to be processed into useful information, the time required to present the information to the operator, the time available to take control of corrective actions, and the time required for the energy management system to execute the action bear significantly on the operator's ability to maintain system stability, reliability, and economy.



Although many innovations in control room instrumentation have evolved in the decades between the time of the early photo, circa 1940, and the modern power system control center, the magnitude of responsibility of the person seated at the console has grown in much greater proportion. The use of on-line computer control systems has led to the elimination of manned substations, making the area under direct control of the system operator much larger; whereas the operator in the historical photo probably controlled power supply to several cities or part of a state, today's system operator may be responsible for meeting the electric needs of a region containing as many as six states.

In a typical control center, several thousand data points are read and transmitted to the control center every two to six seconds. Network power flows adjust to changes in generation or to switching operations instantly. But the time and information loop that links data, the computer, and the operator means that the effect of power flow changes are not seen by the operator as displayed information until from four to eight seconds after an actual change takes place.

Two seconds is considered to be a critical amount of time in human information processing. Delays longer than two seconds may disrupt the operator's short-term memory and impede problem solving.

Growing complexity

Electric power networks and the nature of the profession of those who control them are best described by one word: dynamic. The concept of continuous change and the ever-present contingency relate not only to system stability and the time-information-decision loop but also to the broader technologic and organizational environments in which power systems are operated.

Several trends in the utility industry's operating practices, the nation's use of energy, and the expanding role of information in our society will continue to challenge reliable, economic power system operations well into the future.

New technologies for electric generation, storage, and transmission promise a more diverse and complex options menu for system operators. Some technologies, such as solar and wind, are not dispatchable in the conventional sense and may have to be integrated with storage systems or used in conjunction with other technologies for optimal benefit. The extent to which independent generation units (wind parks, low-head hydro, industrial cogeneration) come into use will also have a direct impact on system operation.

For reasons of economy and reliability, power systems are growing increasingly interconnected; the North American Electric Reliability Council reports that in 1982 the nation's bulk power transmission network was being used closer to its limits than ever before. But although this trend has produced real gains for utilities in the form of economic energy transfers, it has also given rise to new concern that when a disturbance occurs on a part of the network, it may not be properly contained. Closely coupled power systems may be more susceptible to disturbances beyond their service territory. In some parts of the country, pool operating centers have been established to better coordinate bulk power flows among systems.

The tremendous expansion in the information processing capabilities of sophisticated computers heralds new opportunities to reduce some of the uncertainties faced by operators. Computers promise to give utilities the ability to predict the effects on power demand of one of the strongest factors outside the control of a utility—the weather. Future control centers will likely incorporate advanced technology for monitoring, modeling, and forecasting local weather and other environmental impacts on systems operation.

Sometimes, however, information can be a double-edged sword, creating new problems in the course of solving the original problem. The development of advanced, automated energy management systems for power networks has permitted the consolidation and remote control of substation operations, giving fewer operators more responsibility for routine and restorative procedures that were formerly shared with substation operators. By replacing manual switching and the like with keyboard controls, computers have made the control room infinitely large, raising the possibility that an individual's limit for assimilating critical information could be exceeded. In the context of a crisis, such a potential bottleneck may extend the period of interruption rather than shorten it.

Thus, while computers are an extremely valuable tool for system operators, increased dependence on them points up the even greater importance of the reflexes and limitations of the person seated at the CRT screen.

EPRI's role

Within this tapestry of issues relating to system operation and the diversity of utility systems and operating practices, where are EPRI's R&D resources woven into the picture and how can they be used to most broadly benefit the industry?

In addition to numerous projects aimed at more-efficient dispatch of fuels and improving the fidelity of system models, the Power System Planning and Operations Program has completed a major survey and analysis of human factors in the design of system control centers. Work will begin next year on development of capabilities to support an advanced digital computer-based power system simulator. And beyond that, EPRI is looking at ways that the emerging science of knowledge engineering can be applied to support operator decision making in contingency management.

The human factors study completed in 1982 involved a detailed survey of design practices in 13 electric power system control centers. Generic information needs of operators were specified on the basis of interviews and observation. Human factor specialists looked at the methods and tools for organizing and displaying information to the operators, and recommended guidelines for improved design and practice.

The contractor, Stagg Systems, Inc., and the subcontractor, Lockheed Missiles & Space Co., Inc., focused on the man-machine interface between operator and power system and the effects of inconsistent and delayed response times on operator decision making. They identified a number of human-engineering deficiencies common to a majority of the sites surveyed.

NERC's ROLE IN SYSTEM OPERATIONS

Formed by the U.S. and Canadian electric utility industries in 1968, the North American Electric Reliability Council promotes the reliability and adequacy of bulk electric power supply through nine regional councils representing virtually all electric utility systems in the two countries. Through two principal committees, NERC provides an industry forum and mechanism for coordination in the engineering and interconnected operations of bulk power systems.

The NERC Engineering Committee conducts seasonal assessments of U.S. and Canadian power system adequacy and reliability; it also develops specific regional reliability criteria, such as generation reserve adequacy, as well as model simulations of bulk power flow.

NERC's Operating Committee develops guidelines essential to reliable operation of interconnected supply systems and monitors conformance through six subcommittees and working groups. The guidelines relate to the development of automatic generation control practices, procedures for scheduling power interchanges, and treatment of inadvertent accumulations of interchange power on the bulk transmission network. The Operating Committee oversees periodic revisions to NERC's *Operating Manual* that is used throughout the utility industry. □

Six volumes of the final report of the human factors review have now been published. To avoid many of the pitfalls identified at other utility control centers, at least 20 utilities have already used these reports as control centers have been replaced or modernized.

Training simulator

Utilities have found that classroom and on-the-job training are inadequate to prepare operators to respond to the full range of system contingencies that can occur during major disturbances. Classroom training, centered on basic engineering principles, is difficult to transfer to on-the-job use, and it is impractical for operators to practice skills on actual operating systems.

If it can realistically portray the system on which the operator works, a computer-based power system simulator allows a trainee to obtain years of experience in a short time without jeopardizing customer service or damaging equipment. Procedures can be repeated as often as necessary; high operator confidence can be achieved if thorough training exposes the operator to potential real-world situations.

The first simulator for training system operators was introduced five years ago. Although the stand-alone configuration, which simulated a generic hypothetical power system, had a relatively low user cost, poor voltage, frequency, and dynamic models limited its usefulness. In response to utility industry demand, at least four energy management system vendors (Control Data Corp., Energy Systems Computer Applications, Inc., System Control, Inc., and Westinghouse Electric Corp.) now offer improved training simulators. Despite the elimination of some of the weaknesses of the first simulator, however, the more recent simulators still have significant limitations in the fidelity with which they mimic actual systems and the dynamic scenarios likely to confront operators.

An upcoming EPRI research project will attempt to design and build an advanced digital simulator capability with sufficiently accurate system models to provide realistic operator training. According to Charles Frank, project manager, "There is a growing need for a simulator capable of training operators for the full range of system conditions in an environment that most nearly duplicates the operator's work environment." Frank says the project will develop a general-purpose simulator capability that individual utilities can incorporate in their system control centers. "Users can then tailor the simulator to meet their specific training needs," he adds. The project schedule calls for the simulator effort to begin in 1984.

The road ahead

Looking at the future of power system operations, there is a revolution incubating in some of the nation's advanced computer development laboratories that could fundamentally affect the way computers are used to assist and inform system operators. It is known as knowledge engineering, or expert interactive systems that not only can tell a user what is happening on a system in terms of information but also can suggest options for possible corrective measures when something goes wrong.

Knowledge engineering is a subfield of artificial intelligence. Some pioneer artificial intelligence programs are already in use in such fields as mineral prospecting, in which years of learning and the judgment of a few true experts are abstracted and encoded into interactive software. This software can put the same expert knowledge at the fingertips of a less experienced, but properly trained, user in a widely transferable program.

Artificial intelligence represents a radically new approach to computer programming and, by extension, to computer applications. In contrast to traditional computer programs, which function in a repetitive, sequential series of calculations, the next generation of computers may employ a heuristic, subjective, and random process that more closely resembles the way people reason and make decisions.

The Power System Planning and Operations Program took the first step in this fascinating area of human-computer synergism with the recent completion of a project by Case Western Reserve University that assessed the feasibility of using associative memories for static security assessment of power system overloads. According to Robert Iveson, program manager, "The project demonstrated that a computer can be 'taught' to watch for situations in which contingencies could result in degraded system security and to provide direction on how to maneuver the system to an improved condition should the contingency occur." The technique was applied on a trial basis in a large power pool in conjunction with more traditional security monitors.

The implications for power systems of this developing technology are enormous. Someday, perhaps within 5–10 years, computers will offer options, not just information, to an operator in the face of any system contingency, suggesting possible solutions and perhaps estimating the cost and probability of each one's success. The ultimate refinement may be the computer selecting the best option and performing the necessary switching to accomplish it. This tremendous potential to augment the system operator's knowledge base demands a constant eye on the future as developments unfold. ■

Further reading

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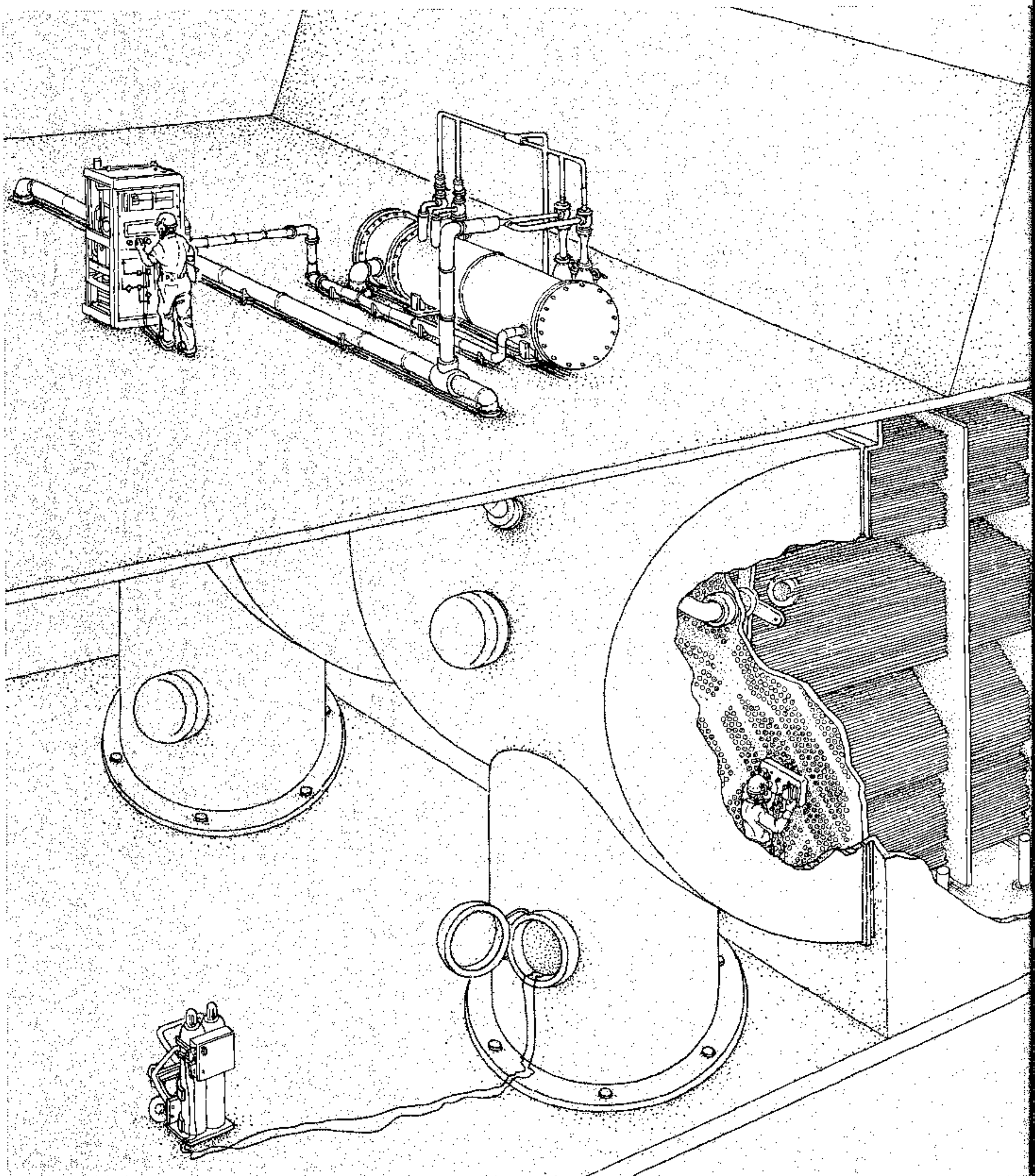
This article was written by Taylor Moore. Technical background information was provided by Robert Iveson and Charles J. Frank, Electrical Systems Division.



The Helium Approach to Leak Detection

Locating a tiny leak in a 70,000-tube condenser can be like looking for a needle in a haystack. A faster, more sensitive method that uses helium as a tracer gas is now in service at over 100 utilities.

Even minute quantities of cooling water leaking into the steam side of the condensers in power plants may deposit corrosive salts in boilers, steam generators, and turbines. The difficulty is not in discovering whether leaks are present, nor in repairing them once they are found. Rather, the challenge to utilities is in pinpointing a leak among the 70,000 or so condenser tubes in a typical power plant. In 1978 EPRI's Nuclear Power Division and Science Applications, Inc. (SAI), adapted a detection method for condensers that uses helium and sensitive helium detectors to locate leaks. This work, along with a 1982 follow-on study performed by NWT Corp. for the Steam Generator Owners Group (SGOG), produced a method that utility personnel have found to be faster and more sensitive than other methods.

Most methods of condenser leak detection, including the one developed by the Nuclear Power Division and SGOG, take advantage of the fact that the pressure in the condenser shell (the steam side of the condenser) is lower than that in the cooling-water tubes (the water side). In these methods the cooling water is valved off, and the tubes and water boxes are drained. Once this is done, the vacuum on the steam side pulls air through any tube leaks. Popular methods of determining which tubes are pulling in air include wrapping the tubes with plastic film or coating them with shaving cream or soap bubbles. Commercial plastic wrap, for example, puckers and wrinkles over tube leaks. These and similar methods, however, are ineffective when it comes to very small leaks, especially tiny cracks in the tube-to-tubesheet weld.

In studies and actual operations, the helium method has proved to be a hundred times more sensitive than soap bubbles and shaving cream, allowing detection of cooling-water leaks smaller than 0.0001 gal/min (0.006 cm^3/s). The process is simple: release helium at one end of selected tubes, draw the helium through those tubes with an exhaust fan located at the other end, and, using a sensitive detection device, monitor the condenser air removal system outlet for traces of helium being sucked into the condenser shell through cracks in the tubes.

Even before the SAI project took shape, tracer gases were being used to find air leaks around valves, drains, seals, and flanges. Because helium is widely used as a tracer gas by other industries, detection equipment, such as the mass spectrometer used for helium and other gases, already existed. SAI's achievement was to adapt the technique for use in the confines of the condenser water box. With this method, a detection team of two trained personnel starts at the top of the water box and works down, successively testing groups of 200–300 tubes. The whole procedure can be carried out in two or three shifts.

First, a plenum, or hood, is pressed against a 1 × 2-ft (0.3 × 0.6-m) portion of the tubesheet. The plenum, sealed around its edge by a rubber gasket, confines the testing to this portion of the tubesheet. Helium from a 5-ft (1.5-m) tank is released through the plenum and down the tubes at the tubesheet. Another team member monitors the condenser offgas with a helium mass spectrometer. If helium is detected in the offgas, it means the tracer gas has been drawn from the water side of the condenser to the steam side through flaws in those tubes being tested. By repeating the test with successively smaller gas plenums, a team can localize the leak to a single tube, which can then be plugged.

The monitoring device picks up the helium traces within 25–90 seconds. This time delay between release of the helium and detection can indicate with considerable accuracy the location of the leak along the length of the tube. Generally, the farther the leak is from the tubesheet, the greater the time delay.

One technical difficulty in using helium inside the water box was the lack of ventilation. The helium or other tracer gas tends to build up quickly in the water box area, thus making it difficult to limit the test to selected tubes. To reduce helium buildup, SAI designed its system so that the initial 15-second burst of helium was followed by a burst of nitrogen. The nitrogen pushes the helium through the tubes and purges them of excess helium at the same time. It was found that the condenser exhaust fans, attached to the water box at the end of the condenser opposite from the one where helium is released, could be used to draw the helium and nitrogen through the tubes and exhaust them to the outside area.

To help utilities use this technique on a routine basis, SGOG hired NWT to survey utilities, identify improvements needed for easier use, and package a system for permanent installation at power plants. In support of this effort, EPRI's Nuclear Power Division contracted with Kinton, Inc., to produce two condenser tube leak job performance aids (JPAs). These JPAs, validated with the SGOG–NWT prototype system at Pacific Gas and Electric Co.'s Moss Landing plant last year, give step-by-step procedures and guidelines that help utilities apply the helium tracer gas technique. The JPAs are available through EPRI.

Over 100 utilities nationwide are successfully using helium to locate leaks in condensers, many on a routine basis. At the Indian Point Unit 3 in Buchanan, New York, where much of the original SAI work was done, the method is used for detecting both air and water leaks. James Gillen, an engineer at Indian Point-3, says the helium method "is simple, easy, nontoxic, and very sensitive."

The SGOG–NWT system was successfully applied to locate air leaks at Rancho Seco, where use of the prototype brought about a reduction in such leakage to less than 5 m^3/h (3 ft^3/min). Robert LeBanc, engineer coordinator at Southern California Edison Co.'s San Onofre plant, also reports success with the system in finding small leaks that let in the brackish seawater used for plant cooling.

As with many maintenance procedures, it is difficult to attribute exact savings to the helium method, but LeBanc maintains that his plant saves about half a day of downtime by using helium as opposed to other methods. If each day the plant is out of service costs the utility $500,000 for replacement power, as is commonly estimated, helium detection may save as much as $250,000 every time it is used. But the real savings from the helium detection method are long term. By detecting tiny leaks other methods cannot, this technique can prevent costly corrosion that shortens the life of boilers, steam generators, and the plant as a whole. ■

This article was written by Carrie McKee. Technical background information was provided by Michael Kolar and John Mundis, Nuclear Power Division, and Roland Coit, Coal Combustion Systems Division.

DOE Issues Electricity Policy Project Report

A new report on the utility industry's ability to meet future electric power demand culminates a yearlong, 30-study look at the industry's economic and regulatory problems.

Ensuring reliable electric power supplies at minimum cost through the end of the century will require the electric utility industry to build a substantial amount of new electric power generating capacity. Yet the industry has little incentive to invest in new power plants now. These are among the central conclusions of DOE's Electricity Policy Project report, released on June 8 by Energy Secretary Donald Hodel. In his cover letter asking some 700 recipients to comment on the inch-thick report and its implications, Hodel said, "The conclusions in this report are intended to provide a springboard for discussion and debate on the critical issues affecting electricity in this country."

The project grew out of issues raised at a meeting of electric industry executives chaired by Vice President George Bush on February 2, 1982, for the purpose of discussing nuclear power issues. The discussion quickly turned to broader topics: the high cost and long lead times associated with building economic new power plants and the overall financial condition of the industry.

On May 13, 1982, the Cabinet Council on the Environment and Natural Resources chartered an interagency working group to study the issues of capital formation and economic efficiency in the electric power industry. The group, chaired by DOE, was given a blank check to launch a major analysis of these issues.

DOE ultimately filled in the check with $2.5 million for 30 studies, most of which were prepared by private consultants. The DOE team was headed by J. Hunter Chiles III, former director of the Office of Policy, Planning, and Analysis, and J. Steven Herod, director of the Office of Electrical Systems Policy and Evaluation. DOE's analysts summarized the 30 studies to produce their report entitled *The Future of Electric Power in America: Economic Supply for Economic Growth*. The summary report can be obtained from the U.S. Government Printing Office (GPO stock number 061-000-00607-9); the backup reports are available from the National Technical Information Service.

Originally, the DOE project was to culminate in policy recommendations to enhance the electric utility industry's ability to meet future national power needs. DOE's strategy changed course, however, when Donald Hodel replaced James Edwards as energy secretary last December. Hodel declined to issue an internal decision paper prepared by Chiles and his staff and presented to the Cabinet Council last November. "When I reviewed the proposed recommendations, it too often seemed to me that they were suggesting additional layers of regulation be inserted into the process," Hodel told a group of energy economists on June 9. DOE project officials explained that "the prescriptive elements of the study were premature. We would have had a hard time getting a consensus on our recommendations."

The summary report, cleared of prescriptive content, now provides a comprehensive analysis of electricity supply and demand trends, financial and regulatory issues, and perceptions of key players in the U.S. electric utility industry. In its own words, it attempts to evaluate whether the electric power industry can be expected to provide adequate power at minimum cost over the foreseeable future. A second objective of the long-term project—to determine what remedies (if any) are appropriate for the federal government to pursue—will be dealt with in a subsequent volume.

Demand Trends

Much of the report's credibility rests on its electricity demand projections. The report's 26-page executive summary was not issued separately because DOE analysts wanted readers to understand exactly how they reached their conclusions regarding future electricity demand.

The report projects that electricity demand is likely to increase by 2–4% annually through the end of the century. In contrast, demand for oil and gas is likely to grow at a much slower pace or actually decline. Electricity demand should grow about as fast as the real level of gross national product (GNP)—about 3% annually in the midrange estimate. Although real electricity prices are expected to rise through the end of the century (on a national average), the prices of competing fuels are expected to rise more rapidly. For this reason, electricity's share of the delivered energy market is expected to increase steadily. It has already grown from 6.2% in 1960 to 12.2% in 1980 and is expected to reach 18.2% in the year 2000.

GNP growth was shown to be the most important determinant of electricity demand. The study shows that if GNP grows faster than 3% annually, electricity demand should increase at an even more rapid rate. Other factors affecting demand for electricity include the delivered prices of electricity and competing energy forms, elasticities of demand for aggregate energy and competing energy forms, changes in income, and changes in technology. Conservation has played an important role in shaping demand trends. The report shows that the United States would have needed 120 more gigawatts of power-generating capacity than it has today if energy-conserving behavior had not been adopted following the 1973 oil embargo.

The DOE demand projection is based on the assumption that national economic recovery will begin soon. Electricity demand, however, did not increase at all in the first half of 1983, in part because mild winter weather suppressed residential heating demand. DOE analysts expect electricity demand to begin growing with GNP in the near future.

Electric Power Supply

If the economy does recover and expand, the nation will need more electric power. If electric power demand grows by 3% annually, the nation will need 438 GW of new generating capability by 2000. This midrange estimate of end-of-the-century supply requirements would necessitate a 57% increase in the amount of capacity that was in place in 1981. About 75% of this future requirement will be due to increased demand, while 15% will be needed to replace retired and deteriorating power plants. The remaining 10% should be added to displace high-cost fuels. Included in the total future capacity requirement is a reserve margin of 20%, which is considered necessary for reliable service.

"Current utility plans for new electric supply do not include all the new supply that is needed to maintain reliable service through the end of the century," the DOE report states. "Unless utilities expand supply beyond current plans, supply will become inadequate to serve demand by 1997 if demand grows slowly, by 1993 if demand grows moderately, and by 1990 if demand grows fast." Electric service could become unreliable even sooner in specific regions, such as New York, New England, Florida, and California, which already lack sufficient economic generating capacity.

DOE points out that many utilities have slowed or abandoned the construction of power plants intended to replace uneconomic oil- and gas-burning facilities. During 1980–1981 there were about 200 such delays or cancellations. DOE estimates that if about half of those power plants could be built or completed on time, consumers would save $20 billion (in net present value, 1982 $) through the end of the century.

The report predicts that many utilities, unable to obtain capital to build economic new coal-fired and nuclear power plants, will continue to rely on oil- and gas-fired generating capacity. Utilities in such areas as California and the Northeast may increase imports of Canadian-generated power. These imports may reduce near-term electricity costs but could increase long-term costs by displacing new domestic generation facilities. "Failure to pursue economic investments in new supply will have a substantial adverse impact on electric prices," claims the report, "while, at the same time, increasing oil import levels and serving as a damper on economic growth. Annual electric bills could be as much as $18 billion higher by 2000 if utilities pursue supply strategies intended only to minimize their capital expenditures."

Decentralized power generation alternatives, such as solar- and wind-powered devices, are expected to enjoy substantial market growth through the end of the century. This growth, however, is not expected to make a significant dent in utilities' end-of-the-century capacity requirements. Although costs of renewable energy systems continue to decline, DOE does not expect adoption of these systems to spread beyond affluent or geographically isolated users until after 1990.

Regulators' Role

What can be done to permit and convince utilities to make the substantial capital expenditures to meet increasing demand? Without making specific recommendations, DOE points a finger at the regulatory system. "By holding returns on utility investments below returns on other investments of comparable risk, rate regulation has made it difficult for many utilities to finance new construction through the sale of stocks and bonds and thus has restricted the construction of new power plants in much of the nation," the report notes. "Although utility managers may perceive the need to make additional investments, it would be imprudent of them to make those investments if they do not believe that the regulatory process will permit them to earn adequate and timely returns."

To provide 438 GW of new capacity by the end of the century, the industry will have to invest about a trillion dollars (in constant 1982 $ with a 5% rate of inflation). Such an investment would be about six times its total current asset base. Will the industry be able to raise such a tremendous amount of capital? Not if current regulatory trends continue, the DOE report implies. The report analyzes the genesis and persistence of the attrition problem, which is the root of the industry's financial weakness. During the 1960s, when electricity rates were constant or declining, utilities were earning returns substantially higher than those authorized by public utility commissions (PUCs). Since the upward cost spiral began in the early 1970s, however, the industry has been earning returns lower than those authorized by PUCs. Cash earnings have fallen at an even faster rate. The incentives to overinvest, which existed 20 years ago, have been replaced by incentives to underinvest. Yet a large segment of the public continues to believe that the utility industry will overbuild in order to maximize profits if rates are raised.

The industry's deteriorating financial condition has been reflected by key financial indexes, such as eroding bond ratings and declining market-to-book ratios of utility stocks. Although the industry received more than $8 billion in base rate relief in 1981 and some other financial improvements have occurred, DOE's analysts believe that disincentives to make necessary investments persist. "The recent improvement in utility financial indicators is at least in part attributable to the reductions in construction plans that have been prevalent over the past few years," they point out. "The excess capacity, which has existed since 1974, has inadvertently created a grace period for the industry. However, even with modest levels of projected demand growth, this grace period is coming to an end."

Even if utilities could raise capital for large-scale expansion, could the nation afford such a drain on total investment resources? "These future capital requirements will not require the industry to claim a larger fraction of gross domestic private investment than it has historically," DOE responds.

What can be done about the basic problem of attrition? The National Governors' Association recommended that Congress pass legislation to allow states to enter voluntarily into regional power planning and/or regional regulation. Before leaving DOE for a private sector position in May, Chiles sought DOE's support for this proposal on the condition that it replaced state regulation, noting that it might move regulators to consider long-term and regional consequences of their actions.

Public Perceptions

In the absence of near-term regulatory reform, however, regulators will continue to be affected by political pressures. To the extent that their actions reflect public attitudes, this situation does not bode well for the industry. According to a public attitude survey, the American people "take for granted that electricity will be available when they want it and are primarily concerned with the price of electricity and the size of their bills. Most Americans think that future electric supply will be adequate without significant new plant construction. If they think new plants are needed, they also tend to believe that utilities can readily obtain the necessary capital to build new plants."

Public confidence in both utilities and PUCs has eroded during the last 10 years, according to the study, as prices have increased. At the same time, Americans have come to feel less threatened by OPEC and have become divided on nuclear energy issues. Utility managers are feeling the difficulty of balancing the increasingly divergent interests of consumers and investors, while regulators must adjudicate disputes among different classes of consumers and even between today's and tomorrow's ratepayers.

"In this contentious regulatory environment, assurance of sufficient long-term electric supplies and improvements in economic efficiency have become issues that are subordinated to near-term issues of price and equity—who pays what part of today's increasing cost," conclude the DOE analysts. "If this situation continues, the inevitable result is likely to be a less reliable, higher-cost electric system."

Recognizing the healthy diversity of perspectives on utility-related issues, DOE is throwing its analysis into the political arena. The analysts will wait—perhaps for a political consensus to form, perhaps for their economic projections to be realized, perhaps for the situation to become more critical as the industry's reserve capacity erodes. In the meantime, they plan to sift through letters commenting on their analysis and gear up for Volume 2. ■

This article was written by Leslie A. Braunstein, a consultant specializing in energy issues.

EPRI Improves Technical Report System

Summary documents and a new distribution data base will allow better targeting for EPRI technical reports, while protecting readers from paper overload.

According to R. L. Rudman, director, Information Services Group, in recent months EPRI has initiated major changes in the way it distributes technical reports. The reason for the changes—which take effect this month—is to ensure that research results can be easily accessed by anyone in an EPRI member utility.

"Since the summer of 1982 we have been working with selected member utilities to analyze how EPRI can be more effective in getting information to them," Rudman explained. "Many utilities have expressed concern about the volume of paper being generated by EPRI. At the same time we were urged to find a way to target information from EPRI so that it matches the professional interests of each recipient more closely, allowing readers to exercise greater control over what they receive."

In June Technical Interest Profile forms were sent to all member utilities that have been receiving technical reports or summaries. The forms asked recipients to choose from a list of research categories, creating an individual Technical Interest Profile for each reader. A new distribution data base has been created from these profiles.

Under the new system the availability of each new EPRI technical report will be announced by a concise, one-page Report Summary distributed according to member profiles in the new data base. This summary provides a synopsis of the research undertaken, including background, objective, and results, and offers an EPRI perspective on contractor work. The summary also highlights the intended audience for the report.

In some instances, readers will find the new summaries give them all the information they need about a particular research project. Others will want to read the entire report, which they can easily obtain from their company's Technical Information Coordinator or library or from EPRI's Research Reports Center. "Individual profiles may be changed by a utility at any time if experience indicates that a revision is desirable," Rudman added.

All member utilities have been encouraged to participate in the new Report Summary program. Member utilities that have been receiving EPRI technical reports or summaries should have already received their profile forms. Interested members who have not received profiles or who would like additional information may contact the EPRI Technical Information Division, (415) 855-2411. Those who receive the profiles are asked to return them as soon as possible, so that the data base can be up-to-date.

Summaries will also be available on a charge basis to non-EPRI members. Information on this is also available from the Technical Information Division.

New Software Policies and Procedures

With the development of an increasing number of EPRI software packages and a greatly increased distribution of existing software, EPRI has been working to streamline procedures and software standards. The purpose has been two-fold: to distribute high-quality software and to give EPRI members easy access to these products.

Over the past year an Institutewide committee analyzed EPRI software issues and made recommendations to senior management. With the adoption of these recommendations, an internal document, "EPRI Computer Code Development and Distribution Principles and Policies," was prepared. Available to EPRI members through Walter Esselman, director of engineering assessment and analysis, this document covers all phases of a software project: definition, development, demonstration, distribution, and maintenance.

"EPRI software will be categorized as either production or research codes," Esselman explains. A production code is one that has been developed for general distribution through the Electric Power Software Center (EPSC) and will be supported by EPRI through the software's lifetime.

A research code is defined as one that was designed to test or prove R&D concepts. "Because of a research code's limited usefulness," Esselman continues, "its distribution will be strictly controlled, requiring the consent of the project manager for each request. These codes will not be distributed by EPSC and will not receive the maintenance support given to production codes." EPRI project managers and their division management personnel will designate the appropriate category for their software.

In response to requests from EPRI members, a master license has been prepared to save EPRI member utilities time and reduce the paperwork required to order EPRI-developed software. Once a master license has been signed, a member utility no longer has to sign a separate licensing agreement for each software package it orders. These requests are processed through EPSC.

An expanded EPSC is working with the EPRI technical divisions and the Technical Information Division to provide efficient service for EPRI software users. The center processes most licenses, distributes software packages, receives error reports, responds to inquiries, assists with installation instructions, and provides reports on these activities to the divisions.

The Electric Power Service Bureau (EPSB), a new activity, provides machine access to EPRI software, with member utilities receiving a discounted computer rate. According to Esselman, the handling of software has been experiencing "growing pains" at a time when EPRI's software development and distribution needs have mushroomed. Member utilities are an integral part of the process—expressing their needs, participating in demonstrations of software, joining users groups, and attending workshops and seminars.

"It has been suggested that each member utility designate a liaison for EPRI software. This could help our efforts to streamline procedures, provide a better channel of communication, improve service, and increase efficiency," Esselman explains. The liaison would provide information within the utility on EPRI codes and on procedures available through EPSC and/or EPSB. These liaisons would inform EPRI of utility needs and experiences in this area. ■

Performance Monitoring for World's Largest Wind Turbine

Earlier this year EPRI signed a memorandum of intent to monitor and evaluate the prototype operation of the world's largest multimegawatt wind turbine generator. General Electric Co. will build the 7.3-MW prototype wind turbine—the MOD-5A—in Kahuku on the windy north shore of Oahu, Hawaii, where it is expected to produce enough electricity to meet the needs of more than 4200 homes.

Hawaiian Electric Co. (Heco) will purchase the wind turbine system from General Electric for $14.2 million and will be responsible for its normal operation and maintenance. General Electric will provide operational support for a five-year period. The U.S. Department of Energy and the National Aeronautics and Space Administration are sponsoring General Electric's design and development efforts for the MOD-5A, the benefits of which will be applied to the Heco project.

EPRI will be involved in the project's operational planning, field qualification, and ongoing performance evaluation. The Institute plans to collect, evaluate, and share all program data with the electric utility industry. As John Cummings, director of EPRI's Renewable Resources Systems Department, explains, "We'll provide an independent, utility-oriented perspective in reviews and performance evaluations and will serve as a central information source for the industry."

The MOD-5A is a scale-up from present technology and represents the newest generation of wind turbines developed under the federally sponsored Wind Energy Program. According to General Electric, a number of innovative features have been incorporated in the final design of the MOD-5A, leading to improved economics and performance capability. The unit will begin producing at 14 mph wind speed, and power output rises to a maximum of 7.3 MW at 32 mph. High-speed cut-out is at 60 mph.

Installation will begin in May 1984 and the first rotation and synchronization with the Heco utility grid is scheduled for May 1985. When fully operational, the unit's 400-ft-long (122-m) rotor is expected to capture enough wind power to generate more than 30 million kWh/yr at the Kahuku site. ■

Zebroski Returns to EPRI

Edwin L. Zebroski, former director of EPRI's Nuclear Safety Analysis Center (NSAC), returned to the Institute this month after two years on loan to the Institute of Nuclear Power Operations (INPO) in Atlanta. He has been named as the chief nuclear scientist in the Energy Study Center under Chauncey Starr, vice chairman of EPRI and director of the center.

During his two years with INPO, Zebroski served as a vice president and chief scientist. He was director of NSAC from its founding in April 1979 until 1981 and was director of the Nuclear Systems and Materials Department in EPRI's Nuclear Power Division from 1974 to 1979.

Zebroski, who has been involved in the field of nuclear energy since the World War II days of the Manhattan Project, came to EPRI after a 27-year career with General Electric Co., where he made many contributions to the technology.

A native of Chicago, Zebroski earned a BS in physics and chemistry at the University of Chicago and a PhD in physical chemistry at the University of California at Berkeley. He has written or been coauthor of about 140 technical publications, is a member and fellow of several professional societies, including the prestigious National Academy of Engineering, and is on the Board of Directors of the American Nuclear Society. ■

CALENDAR

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

SEPTEMBER

20–22
Workshop: Heat Rate Improvement
St. Louis, Missouri
Contact: Anthony Armor (415) 855-2961

21–23
Human Factors for Assessing and Enhancing Power Plant Maintainability
San Mateo, California
Contact: Howard Parris (415) 855-2776

27–28
Power Plant Reliability and Availability Analyses
New York, New York
Contact: Jerome Weiss (415) 855-2495

27–29
PWR Radiation Control
Palo Alto, California
Contact: Howard Ocken (415) 855-2055

OCTOBER

11–13
Value of Service Reliability to Consumers
St. Louis, Missouri
Contact: Ronald Wyzga (415) 855-2577

12–14
Seminar: Fuel Supply
New Orleans, Louisiana
Contact: Colleen Hyams (415) 855-2620

17–21
Seminar: Fault Tree and Event Tree Analysis
Dallas, Texas
Contact: David Worledge (415) 855-2342

19–21
Workshop: Generator Monitoring and Surveillance
Dallas, Texas
Contact: Dharmendra Sharma (415) 855-2302

26–27
Meeting: 13th Semiannual ARMP Users Group
Palo Alto, California
Contact: Walter Eich (415) 855-2090

31
Seminar: FGD Chemistry and Analytic Methods
New Orleans, Louisiana
Contact: Dorothy Stewart (415) 855-2609

31–Nov. 1
Seminar: Cogeneration Modeling
Atlanta, Georgia
Contact: David Hu (415) 855-2420

NOVEMBER

1–4
Symposium: Flue Gas Desulfurization
New Orleans, Louisiana
Contact: Tom Morasky (415) 855-2468

2–3
3d Annual Contractors' Conference on Coal Gasification
Palo Alto, California
Contact: George Quentin (415) 855-2524

2–4
Two-Shift Cycling of Fossil Plants
Chicago, Illinois
Contact: Frank Wong (415) 855-8969

10–11
5th Annual EPRI NDE Information Meeting
Palo Alto, California
Contact: Soung-Nan Liu (415) 855-2480

13–16
1983 National Fuel Cell Seminar
Lake Buena Vista, Florida
Contact: Edward Gillis (415) 855-2542

DECEMBER

6–8
Seminar: PCB
Atlanta, Georgia
Contact: Gilbert Addis (415) 855-2286

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

LIQUID-PHASE METHANOL SYNTHESIS

Exploratory research on the liquid-phase methanol process with a liquid-ebullated catalyst bed reactor system was conducted at Chem Systems, Inc. (CSI), with EPRI funding (RP317-1 and -2). The results of this effort were reported in the July/August 1981 issue of the EPRI Journal. *It was concluded that the limited continuous laboratory process development unit (PDU) test results raised some questions concerning the feasibility of liquid-phase methanol synthesis and that further demonstration of the process concept was required. Exploratory work at CSI proceeded, without EPRI funding, to further assess the feasibility of a process variant known as the liquid-entrained slurry reactor system. This effort was privately funded by Air Products and Chemicals, Inc. (APCI) and Fluor Corp. Based on the promising results, APCI entered into an agreement with DOE to conduct a 3½-year project to demonstrate the technical feasibility of both variants of the liquid-phase methanol process. EPRI then joined with APCI, DOE, and Fluor to fund the project (RP317-3).*

The liquid-phase methanol synthesis process uses an inert circulating liquid having a high boiling point to remove heat and control the temperature of the highly exothermic methanol synthesis reactions:

$$CO + 2H_2 \rightleftarrows CH_3OH \quad (1)$$
$$\Delta H_1 = -21.7 \text{ kcal } (-90.8 \text{ kJ})$$

$$CO_2 + 3H_2 \rightleftarrows CH_3OH + H_2O \quad (2)$$
$$\Delta H_2 = -11.8 \text{ kcal } (-49.9 \text{ kJ})$$

Unlike the commercially available Imperial Chemical Industries (ICI) and Lurgi processes, the liquid-phase methanol synthesis is being developed to process a coal-derived synthesis gas rich in CO without additional shift conversion. The ability to process such gases derives from using the circulating liquid for heat removal rather than recycling cooled unconverted effluent gas.

The jointly funded research improves the prospects for technical success because it provides the financial support required to prove the technical feasibility of the concept, and it broadens the technical expertise of the project team by adding the know-how of a major producer of chemicals (including methanol) and of a major engineering and construction company. The joint project incorporates three major interrelated tasks.

- Design and installation of a liquid-phase methanol PDU at LaPorte, Texas
- A supporting laboratory research program
- Process demonstration by operation of the PDU

The PDU at LaPorte

The APCI plant in LaPorte, Texas, is an ideal site for the PDU because it can provide the PDU operation with relatively large amounts of synthesis gas ($CO + H_2$), various utilities, and maintenance facilities. DOE-owned equipment from an analogous PDU that produced methane was assigned to the project for incorporation into the new PDU at LaPorte. Prior to relocating the PDU to a vendor's shop in Texas for inspection and renovation, APCI conducted a safety examination and process engineering design review of the existing PDU equipment at its original location in Chicago, Illinois. Based on these findings, APCI developed detailed plans and specifications for the repair, modification, and installation of the PDU.

The demonstration of the liquid-phase methanol process was planned with two reactor systems: a liquid-ebullated catalyst bed and an entrained slurry catalyst. A unified design concept, which will provide the capability of operating in both modes with a single reactor system, was proposed for the PDU. A simplified process flow diagram is shown in Figure 1.

The liquid-fluidized methanol synthesis reactor is an extension of the ebullated catalyst bed reactor concept that is being commercially used in the H-Oil process and was successfully tested in the H-Coal process. From this work, it is known that a properly designed distributor tray is essential and that the ebullating pump, which is designed for slurry service, recycles liquid to the reactor without filtration. At EPRI's request, the following design modifications have been considered.

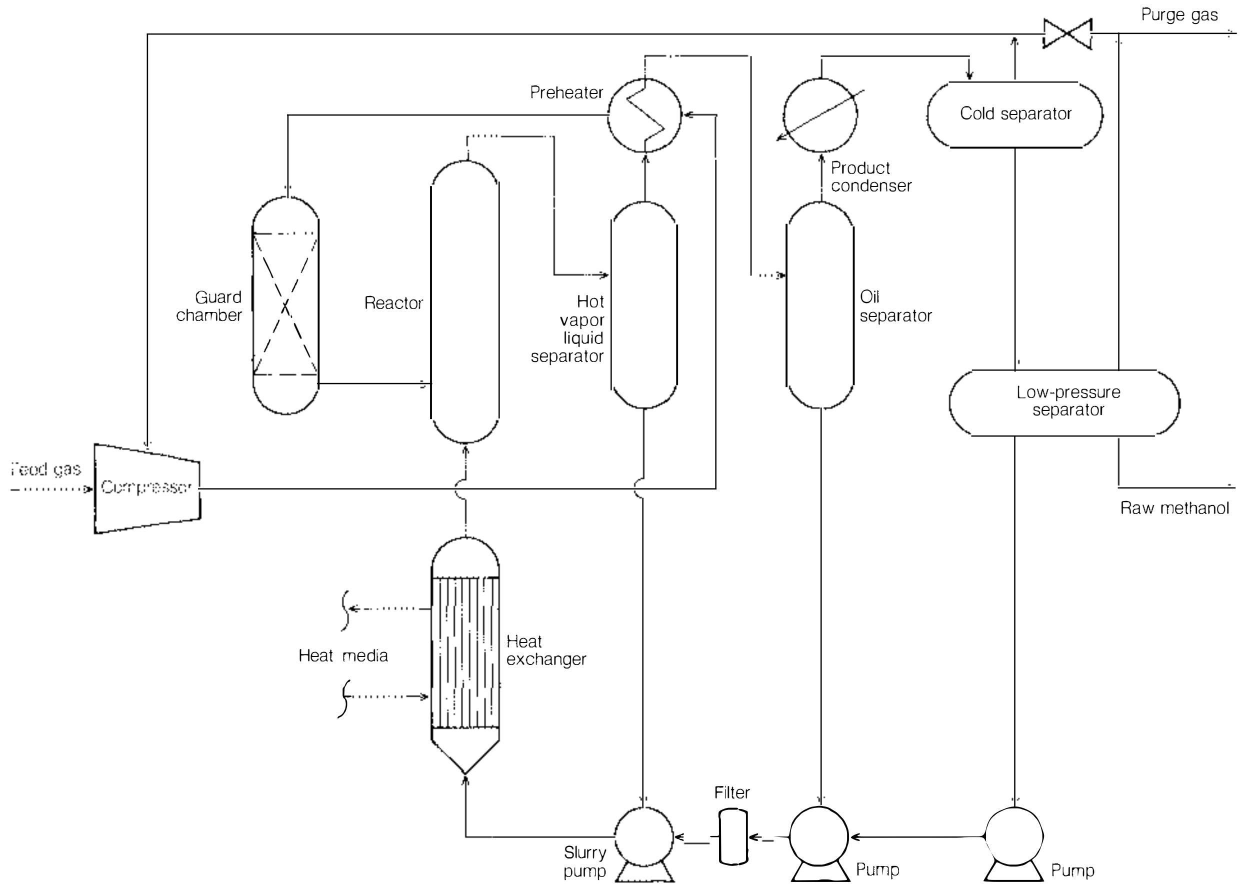
- Installation of a properly designed distributor tray in the modified reactor inlet plenum
- Allowance for the proper freeboard above the catalyst bed
- Removal of the filters from the discharge line of the slurry pumps so that catalyst fines can recirculate to the reactor

Catalyst fines will leave the reactor system only by entrainment with the vapor gas mixture leaving the high-pressure separator. This will also apply to the entrained slurry operation mode.

To help in the design of the liquid-ebullated reactor, APCI requested Hydrocarbon Research, Inc. (HRI)—the original developer of ebullated-bed technology—to conduct cold-flow studies with a sample of United Catalyst, Inc.'s catalyst (developed under RP1656) to determine the fluidization characteristics and the attrition resistance of the catalyst in both fresh and reduced forms. Based on these results, HRI is providing the design for the distributor tray, the inlet plenum chamber, and the required freeboard above the catalyst bed.

Because the catalyst is sensitive to poisoning by iron carbonyls, EPRI requested that the metallurgy of the liquid-phase methanol PDU be reviewed to assess the unit's

Figure 1 Simplified process flow diagram for the PDU at LaPorte, Texas. The feed gas is compressed, preheated, and passed through a guard chamber designed to remove iron carbonyls. The feed gas then enters the reactor, where it reacts in the presence of a catalyst suspended in a mineral oil. The reactor effluent enters the hot vapor-liquid separator. The liquid phase, composed of mineral oil containing suspended catalyst particles, is taken by the slurry pump and is recycled back to the reactor through the heat exchanger, where the slurry is cooled to remove the heat of reaction. The vapor phase is cooled in two stages to separate the entrained mineral oil and to condense the reaction product. The unreacted gas, separated in the cold separator, is partially recycled to the reactor.



ability to operate in an atmosphere of high CO partial pressure without the formation of metal carbonyls. The review concluded that some of the equipment, piping, and fitting require a metallurgy upgrade. For the reactor itself, internal cladding with copper was recommended. In addition, the need for a guard bed was confirmed to protect against contamination by iron carbonyl, which will likely be formed in the makeup and recycle gas compressor

EPRI has also expressed concerns regarding the adequacy of the catalyst temperature control in the reactor system proposed for the LaPorte PDU and suggested two alternative reactor systems for evaluation. APCI and CSI have not shared EPRI concerns with respect to potential problems with temperature control. As a result, they have recommended the deletion of a plan to test a tube bundle insert in the existing slurry reactor, although such an insert has been successfully used to control the temperature in the Kolbel slurry reactor for Fischer-Tropsch synthesis.

The construction work at LaPorte is on schedule and the PDU operation is expected to begin by the end of this year.

Laboratory research

Laboratory research is being conducted simultaneously with, and in support of, the design, installation, and operation of the PDU at LaPorte. The R&D is being performed both at APCI and at CSI (as subcontractor to APCI).

To facilitate the R&D, additional laboratory equipment was purchased for both APCI and CSI, including a gas-phase screening reactor system and a stirred autoclave reactor for APCI and a supplemental skid for the existing laboratory PDU at CSI. The supplemental skid contains the new reaction equipment required for the slurry operation. The construction and initial shakedown test of the additional equipment were completed earlier, and the new laboratory equipment is now in operation at both APCI and CSI.

The APCI R&D effort includes the following tasks.

- Preparation of highly active catalyst samples specifically designed to work efficiently in gas/liquid/solid systems
- Laboratory screening and testing of the new catalyst samples in a stirred autoclave
- Reactor scale-up and hydrodynamics
- Miscellaneous experimental support

The CSI R&D effort incorporates the following tasks.

- Laboratory screening and testing of commercially available slurry catalysts in a stirred autoclave
- Testing and optimizing the in situ catalyst reduction techniques
- Process demonstration in the continuous laboratory PDU with the catalyst charge prepared for the LaPorte operation

Work on preparation of new catalyst samples is proceeding at APCI. As they become available, the new samples are tested in both the gas-phase reactor and the stirred-slurry autoclave. A total of 23 new catalyst formulations will be prepared and tested. The catalyst preparations are selected from the following three groups: supported mixed oxides, unsupported mixed oxides, and Raney alloys. Thus far, no breakthrough has been reported in the effort to find a substitute for the CuO-ZnO-Al_2O_3–based catalyst, which is commercially used in low-pressure gas-phase methanol synthesis.

A review of the hydrodynamic data on three-phase reactors and their applicability to the liquid-phase methanol reactor design and scale-up was completed. The review was based on data and correlations taken from the literature and the cold-flow studies conducted at APCI on the 5- and 12-inch-diameter (127-mm and 305-mm) columns for the SRC-1 and Fischer-Tropsch processes. In addition, experiments were conducted in a stirred autoclave made of plexiglas, using an air-water-sand system to measure the volumetric gas-liquid mass transfer coefficient (k_La). It was concluded that additional cold-flow hydrodynamic studies at ambient conditions are not likely to yield useful data beyond those available in the literature. It was therefore recommended that gas holdup and gas-liquid mass transfer coefficients be measured in the CSI laboratory PDU and in the LaPorte PDU at process conditions (pressure and temperature) with Freezene-100 oil. A plan is also being formed to measure the volumetric gas-liquid mass transfer coefficients in the stirred autoclave reactors at process conditions, using the real fluid media. This effort will provide better values for the gas-liquid mass transfer coefficients and Henry's law constants, which will be used in data analysis and reactor modeling. Progress was also made in the effort to develop reactor models for a continuously stirred tank reactor with steady flow of gas through a batch slurry phase and a dispersed-flow tubular reactor with concurrent upflow of slurry and gas.

Significant work is also being performed in the miscellaneous experimental support task. Various materials are being evaluated to determine their effectiveness in removing iron carbonyl. The experimental results will provide a basis for selecting the material to be placed in the LaPorte guard bed.

Early in 1982 CSI conducted a liquid-fluidized operation in the laboratory PDU, using one of the catalyst samples prepared by United Catalysts for EPRI and a 25% CO feed gas. Although the catalyst activity maintenance and the catalyst loss by attrition were markedly improved compared with the earlier results, the performance was still not fully satisfactory. It was also determined that this particular catalyst batch was not properly calcined. Two additional laboratory PDU operations are scheduled for the third quarter of 1983 with two catalyst samples from United Catalysts that were properly finished (calcined), with modified reactor internals and no filters in the liquid recycle lines. The tests will be conducted in the liquid-fluidized mode with a high-CO feed gas.

Other experiments were conducted in a stirred autoclave with a commercially available powder catalyst and a high-CO feed gas at two system pressures: 1500 psig (10.3 MPa) and 500 psig (3.4 MPa). The objective of these experiments was to determine the catalyst activity, selectivity, and life projection when operating with high-CO gas and a slurry catalyst. Activated-carbon guard beds were employed to prevent catalyst poisoning by removing iron carbonyl that was present in the feed gas because of prior formation at high CO partial pressure Although a rapid catalyst deactivation was observed from the start of a 1500-psig run, the performance of the 500-psig run was encouraging for over 900 hours of operation. Subsequently, the catalyst in the 500-psig run also lost its activity rapidly. The rapid loss of catalyst activity presumably indicates a sudden catalyst poisoning by an agent that was absent earlier in the run. A comprehensive laboratory test program has been undertaken by APCI to determine the underlying cause of the rapid catalyst activity loss that was experienced. The ongoing laboratory tests are searching for known catalyst poisons (e.g., chlorine, sulfur) in the feed gas, in fresh and circulating oil, and in fresh, used, and deactivated catalyst samples. The tests will also look for changes in the catalyst composition and physical properties. X-ray diffraction will be used to determine whether the copper in the catalyst was recrystallized during the operation.

EPRI is hopeful that the ongoing laboratory tests will clarify the nature of the difficulties experienced in the slurry autoclave tests with high-CO gas. The knowledge gained will also be helpful in the planning and execution of the laboratory PDU experiments scheduled for later in the year. *Project Manager: Nandor Hertz*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

INTEGRATED ENVIRONMENTAL CONTROL

Stringent environmental regulations for coal-fired power plants have escalated the costs of environmental controls to as much as 40% of total plant investment and 20% of operating costs for new units. The complexity of environmental controls for flue gas emissions, liquid and solid wastes, and heat and wastewater management not only contributes to high operating costs but adversely affects power plant availability. The high costs and complexity of environmental controls are compounded when the design approach primarily considers the steam generator and turbine as an integral unit and treats emission control and waste management as independent subsystems. In an attempt to reduce environmental control complexity and simplify operating procedures, utility industry engineers have increasingly pursued a design approach that fully considers interactions of environmental control components with one another and with the boiler/turbine. This systems perspective of power plant design can lead to an integration of environmental control functions and maximize plant compatibility with fuel and site characteristics. EPRI has initiated integrated environmental control (IEC) research to develop, promote, and improve the systems engineering approach to plant design.

The objective of the divisionwide IEC effort is to minimize environmental control system cost without compromising performance or availability. This research is expected to produce engineering guidelines for the selection and design of emission control and management systems that are most compatible with constraints imposed by site and fuel characteristics and the requirements of other emission controls.

Design studies

Development of a strategy for integrated design began in July 1982 by Stearns-Roger Engineering Corp. (RP1609-1). The strategy is intended to guide the design process to systematically consider all potential interactions between components of the environmental control system, between the environmental control system and the boiler/turbine, and between site-specific and fuel-specific factors. In simplest form the strategy is an identification of the issues to be considered during the design process, the order of that consideration, and milestones for major design decisions. Decisions of first-order importance in eight technical disciplines are identified early in the design process so the most significant interactions can be accounted for without a complete preliminary design. If successful, the strategy will prevent design decisions in any one control discipline (e.g., heat rejection or solid waste) from being made without considering their influence on other controls. The basic elements of the strategy have been assembled and are being applied to 12 hypothetical coal-fired power plants with unique site and fuel characteristics that span a broad range within the U.S. utility industry.

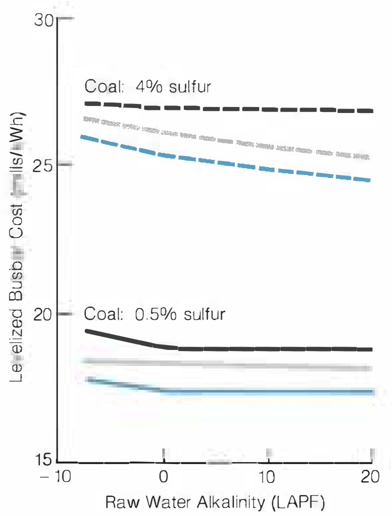
In addition to the environmental control disciplines considered in the strategy (SO_2, heat rejection, NO_x, particulate, water and wastewater management, solid wastes), site selection and fuel selection can be explicitly treated as control techniques by considering different combinations of site and fuel. As the user progresses through the strategy, the potential environmental control configurations are reduced to a small, manageable number for consideration in preliminary engineering studies.

As an example, at a hypothetical northeastern site, application of the strategy to a medium-sulfur coal identified 9 viable IEC configurations to be considered for preliminary engineering; 13 were identified for a Gulf Coast site with a Texas lignite; 16 for a southwestern site with a Utah coal. Engineering screening studies for these and other sites are under way to estimate levelized costs, which, in combination with a technical evaluation, will identify the most promising candidates for final design.

Once a particular IEC configuration has been selected, integration between individual emission control components can be pursued to similarly reduce complexity and cost. Some integration concepts combine two control functions into one (e.g., spray dryer and fabric filter, combining control of SO_2 and particulate, or fixation of scrubber waste with fly ash and lime), while others consolidate operating requirements (using wastewater from one component as makeup for another). Some concepts are straightforward in application, do not risk failure to achieve performance or availability goals, and thus can be currently applied. Others are novel and unproven, and although they offer the potential for more-significant savings, they present risks to achieving performance or availability goals. Under RP1609-2, Black & Veatch Consulting Engineers have estimated savings attributable to conventional (low-risk) integration concepts applied to a southwestern plant for a range of fuel properties, SO_2 removal, and wet scrubber makeup water alkalinity. Figure 1 shows the influence on levelized costs of the environmental control system (limestone scrubber, particulate control, waste disposal, and management of heat and wastewater) for designs produced from three approaches.

- Separate disposal of ash and scrubber waste; fresh scrubber makeup water

Figure 1 Comparison of environmental control cost sensitivity to raw water alkalinity for two coal sulfur levels (fabric filter, solid curves; electrostatic precipitator, dashed curves). Costs are shown for a conventional approach (black), integrated-partial wastewater reuse (gray), and integrated-full wastewater reuse (color). A liquid absorption potential factor (LAPF) can be used to describe changes in the available alkalinity in scrubbing liquor for SO_2 removal. The LAPF is defined in terms of the molal concentrations of the following species according to the relationship: LAPF = $2 \cdot [Mg^{++}] + [Na^{+}] - [Cl^{-}]$. As LAPF becomes more positive, SO_2 removal is improved; as it becomes more negative, SO_2 removal is inhibited.



- Codisposal of ash and scrubber waste; partial wastewater reuse
- Codisposal of ash and scrubber waste; maximum wastewater reuse

The results show savings in levelized cost for two coal sulfur levels and scrubber makeup water alkalinity. Levelized cost savings are greatest for high-sulfur coal and the most alkaline water—by as much as 15% of total environmental control costs. The results are specific for the southwestern location; savings from wastewater reuse (reduction in evaporative ponding requirements) for power plants complying with zero water discharge regulations would be higher in locations other than the Southwest, where evaporation can provide a significant sink for water.

Pilot plant tests

A significant portion of the IEC effort is dedicated to providing experience with integration concepts through pilot plant tests. Integration concepts such as wastewater utilization, codisposal of waste products, and combined SO_2-particulate control (with conventional wet scrubbers or spray dryers and electrostatic precipitators or fabric filters) are being studied at the Arapahoe Test Facility. These tests are being conducted by Brown & Caldwell at the 2.5-MW (e) IEC pilot plant (RP1646-4). The results will permit the influence of environmental controls applied to one medium (e.g., flue gas SO_2 removal) to be interpreted in terms of other media (e.g., wastewater quality) and heat rate factors (e.g., acid dew point, auxiliary power requirements). The interrelationships among media will be evaluated for different wastewater utilization schemes (cooling tower blowdown as wet scrubber, mist eliminator, and spray dryer makeup), various combinations of flue gas temperature, SO_2 and particulate concentration, and stringency of environmental control. Requirements for acceptable turndown and transient conditions (such as load swings or startups) and recommendations for operation/maintenance will be documented. The results will provide guidelines for applying cost-saving integration concepts without risk to meeting performance goals or availability.

A fabric filter–wet limestone scrubber combination (referred to as IEC Configuration No. 1) is currently being tested with several simulated compositions of cooling tower blowdown for scrubber makeup, and different inlet SO_2 concentration and removal. Engineering properties of the solid wastes (fly ash, scrubber wastes, with various lime additives) are being determined for waste disposal requirements. Characteristic of this configuration are the relatively low levels of fly ash in the gypsum by-product, which, depending on the design and operation of the water management system, could provide a by-product low in impurities. Flue gas particulate removal is relatively independent of ash properties, but pressure drop is relatively high (compared with that for electrostatic precipitation). One integration concept being studied is the influence of low flue gas temperature (as generated from waste heat recovery systems) on wet scrubber SO_2 removal, dewatering plant requirements, and waste product characteristics affecting disposal. An actual waste heat recovery system is not used at Arapahoe, but the influence on flue gas temperature is simulated through selection of air heater flue gas exit temperatures. A test apparatus that simulates a regenerative waste heat recovery system is being evaluated to determine materials of construction and cleaning requirements through pilot-scale testing at the Scholz plant of Georgia Power Co. (RP1881). Scrubber flue gas inlet temperature was decreased from 250 to 175°F (120 to 80°C). Preliminary analysis of the results indicates a decrease in limestone slurry temperature from 103 to 97°F (39 to 36°C) and increased total dissolved solids over baseline levels by 40%—with calcium, dissolved sulfate, and silica the constituents most affected, and chlorine and magnesium unchanged. Analysis of crystal growth and solids dewatering properties is in progress. Further tests will study higher limestone slurry temperatures.

The IEC projects are being coordinated with projects in Air Quality Control; Desulfurization Processes; and Heat, Waste, and Water Management programs of the Environmental Control Systems Department. Selected projects pertaining to coal quality and fan design within the Fossil Fuel Power Plants Department also relate to IEC work. The results produce guidelines for integrated plant design, which will propose a general design strategy, report experience with integration concepts at the IEC pilot plant and industrywide, and evaluate such concepts in terms of cost savings and availability. These guidelines will be developed with assistance from the steering committees, consisting of representatives of utility companies and architect-engineering firms. Although of greatest benefit for new plants, the guidelines will be applicable on retrofit designs to improve thermal or environmental performance or to ease operating requirements. A preliminary volume will be issued late in 1984. *Project Manager: J. Edward Cichanowicz*

POWER PLANT PERFORMANCE MONITORING

Faced with lower-than-expected load growth and higher-than-traditional interest rates, utilities have deferred new generating units in recent years. As a result, existing units will be expected to operate longer and without deterioration of efficiency or reliability. With rising fuel costs and new incentives from the public utility commissions, improved heat rate has become a primary focus for utilities. A remarkably large margin separates the most efficient plants (~9000 Btu/kWh) from the least efficient (>13,000 Btu/kWh). In fact, in a recent EPRI survey (RP1403-3), a potential average improvement of 400 Btu/kWh was thought to be achievable by the surveyed utilities themselves. However, because of the lack of reliable instruments to measure performance accurately, many power stations still find it a difficult task to maintain maximum efficiency and availability.

Conversely, those stations that traditionally achieve the best heat rate—such as Belews Creek and Marshall (Duke Power Co.), Bull Run (Tennessee Valley Authority), and Amos (American Electric Power Co., Inc.)—have adopted in-plant procedures for continuous monitoring of component heat rate. Programs to improve instruments and diagnostics will allow utilities to monitor plant component performance and determine when deteriorating or less-than-optimal operating conditions are occurring. Performance monitoring leads to corrective actions and thereby improves unit heat rate and availability.

Table 1
EFFECTS OF KEY PLANT PARAMETERS ON HEAT RATE

Plant Parameter	Incremental Change	Penalty on Heat Rate (Btu/kWh)
Main steam temperature	−10°F (−6°C)	+10
Main steam pressure	−10 psig (−69 kPa)	+3
Reheat temperature	−10°F (−6°C)	+10
Back pressure	+1 in Hg (+3.4 kPa)	+200
Excess O_2	+1%	+30
Flue gas temperature	+10°F (+6°C)	+36

EPRI has undertaken a major effort to develop advanced computer-based instrumentation systems and algorithms for plant performance monitoring and analysis. Specific goals are to improve unit heat rate, unit availability, and economic system dispatch. Detailed analysis of plant performance can be used by plant engineers, operating personnel, and staff in the power supply group and system control center. At least 1% in plant efficiency can be gained.

EPRI's Coal Combustion Systems Division (RP1681) and Electrical Systems Division (RP2153) are jointly sponsoring the research. (See the R&D Status Report of the Electrical Systems Division in this issue for a description of the research from a systems viewpoint.) Potomac Electric Power Co. (Pepco) will be the host utility and prime contractor and its Morgantown Unit 2, a coal-fired 575-MW unit, will be the demonstration site for all new developments and innovations.

RP1681, which began in October 1982, will proceed in two stages. The first phase will use current or soon-to-be-available instrumentation to continuously monitor and analyze plant performance in such fundamental operating areas as excess air, environmental control and boiler and turbine cycles. These areas all show potential for short-run improvement. A second phase will extend the system developed under Phase 1 to include advanced devices and operating procedures to further refine the performance monitoring scope and accuracy. This stage will emphasize such issues as instantaneous coal flow and Btu measurement, the effects of coal grind size on boiler performance, and tube wastage mechanisms. Phase 2 will thus require a more substantial R&D effort and will be completed in the late 1980s.

Boiler performance monitoring

Plant operation at off-design conditions can severely penalize heat rate. Table 1 shows some of the typical plant operating parameters that can adversely affect the heat rate when they are not at the optimal point. Such off-design conditions may be indicative of the tendency to compensate for inadequate and unreliable instrumentation by operating with a higher-than-necessary safety margin. With proper implementation of state-of-the art instrumentation, operators can be guided to run their plants more efficiently and with greater confidence.

Many boiler operating parameters affect the energy input side of the heat rate equation. For example, reductions in excess air and in exit-gas temperature lower the flue gas flow rate, thereby reducing stack loss and minimizing fan power. The thermodynamic and cost trade-offs among these parameters are often not well defined. Figure 2 illustrates the general relationships among excess oxygen, exit-gas temperature, and heat rate. Of course many other considerations, such as boiler slagging and unburned carbon, determine optimal levels of excess air and exit-gas temperature.

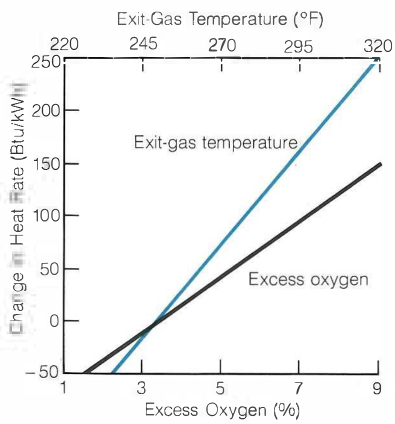


Figure 2 The effect of variations in boiler operating parameters (exit-gas temperature and excess oxygen) on heat rate. An efficient plant should nominally operate at 3–4% excess oxygen and at an exit-gas temperature of 250–260°F (121–127°C).

- When the oxygen level decreases to a given point, the amounts of unburned carbon monoxide increase dramatically, raising the potential for increased particulate emissions, explosions, and fires.
- A reduction in excess air may increase the rate of slag buildup and tube wastage in the furnace.
- The level of excess air may influence corrosion and fouling in the superheater and reheater zones.
- A reduced airflow rate lowers the velocity of gases near the boiler tubes, leading to poorer convection heat transfer and perhaps lower steam temperature. The result can be reduced turbine cycle efficiency.
- The lower the exit-gas temperature, the greater the potential for corrosion from acid dew-point condensation in the boiler back-end equipment and ductwork.

Accurate instrumentation is critical for achieving and maintaining operation of the plant at the optimal level. EPRI will examine three main areas for instrumentation in the boiler: furnace monitoring, back-end monitoring, and advanced coal and combustion measurement devices (Table 2).

Turbine cycle monitoring

The turbine generator affects the energy output side of heat rate improvement. An improvement of 1% in turbine efficiency can improve the heat rate by about 80 Btu/kWh.

Table 2
INSTRUMENTATION FOR PERFORMANCE MONITORING STUDY

Furnace	
Flue gas stratification	
Unburned carbon (excess air)	
Primary and secondary airflow	
Waterwall tube wastage and slagging	
Superheater/reheater tube wastage and fouling	
Flame and superheater/reheater temperature	
Gas in flame zone	
Wall heat flux	
Back End	
SO_3 concentration (extractive or continuous)	
Acid dew point	
Corrosion	
Stack loss (flow and temperature)*	
Advanced Measurement	
Instantaneous coal flow and Btu value	
Burner fuel-air ratios	
Carbon loss (carbon content in fly ash)	

*Measurements of the Btu content of stack gas leaving the power plant is an alternative to measuring coal flow and Btu input rate into the boiler.

In many cases, utilities can aim simply to minimize losses caused by off-design conditions, as well as improve full-load turbine efficiency. In fact, the turbine–feedwater heater cycle is one place that offers opportunities for considerable overall improvement. The study will adopt or develop performance calculation routines for cycle analysis. These algorithms, processed by computer systems, will allow continuous analysis of the turbine-feedwater cycle (as well as the boiler) and guide utility personnel in achieving optimal plant heat rate. On-line monitoring of turbine performance is also useful in achieving real-time economic system dispatch.

One of the important factors in assessing turbine performance is the position of the control valves, which in turn can provide information for developing loading strategy. Currently, it is difficult to determine if a turbine is operating at optimal valve points for a given MW loading. Thus, one of the tasks of this research will be to develop a way to determine the control valve positions. This can be done either physically or inferentially (by measuring the pressure ratio across the valves or, alternatively, across the valves and the turbine first stage).

Upgrading instrumentation systems will be another focus of the EPRI work. Pepco is taking the following steps to increase the reliability of turbine output measurements.

- Improvement in turbine performance measurements based on the EPRI-sponsored simplified ASME turbine test procedure.
- Improvements in measuring turbine exhaust pressure, a key parameter in maintaining heat rate, as shown in Table 1.
- Design of an instrumentation system to aid in-place calibration of pressure and temperature sensors. Higher-accuracy deadweight gages and platinum resistance temperature detectors will be necessary to improve the absolute accuracy of the system and to ensure long-term repeatability.
- Development of a fully three-phase, solid-state, high-accuracy, high-resolution watt-hour metering system.
- Determination of major packing leakage from the high-pressure turbine first stage into the intermediate-pressure turbine. This measurement has a significant impact on high-pressure turbine work (MW), intermediate-pressure turbine inlet enthalpy mix calculation, and the resulting intermediate-pressure turbine efficiency calculation.

The high cost and complexity of the full ASME test of turbine performance have long discouraged utilities from undertaking such tests. The PTC-6 test code committee has now approved an alternative, simplified ASME procedure that is less costly without sacrificing accuracy. EPRI has successfully demonstrated this alternative testing at Laramie River Unit 3 of Basin Electric Power Cooperative with results comparable to those of the full ASME test (RP1878). An accuracy of ±0.37% was obtained. The current research will assess the value of the new procedure in periodic or continuous turbine performance monitoring.

Auxiliary systems

RP1681 will also investigate the potential for upgrading instrumentation for monitoring auxiliary equipment. For example, efficient operation of the condenser requires monitoring back-end pressure conditions and heat transfer characteristics. In addition, performance analysis in conjunction with the boiler turbine cycle is required. Other auxiliary parameters include measurement of fan and pump efficiencies, major motor power consumption, air heater temperature transients, and particulate emission of precipitators (optimized for minimum power consumption).

The overall goal of this project is to develop an advanced instrumentation system that coordinates new devices and techniques for power plant performance monitoring and measurement. This integrated system is expected to improve overall plant efficiency by 1–2%. *Project Manager: Frank K. L. Wong*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DISTRIBUTION

Oilless transformer

Distribution transformers in common use today use oil as an insulant and as a heat transfer medium. This design has given good service for many years. During this time, its characteristics have been optimized in regard to cost, overload capabilities, losses, and so on. It has long been recognized, however, that oil-insulated distribution transformers are subject to destructive failure when arcing occurs under the oil. This arcing can cause a rapid rise in pressure from the decomposition of the oil. The rapid rise in pressure can blow off the transformer cover and bushings or can rupture the tank. Measures to materially reduce or eliminate these destructive failures have not been entirely successful. This research project (RP1143) is an attempt to address the problems by eliminating the oil and hence the source of the rapid pressure rise. The design goals are to produce an oilless distribution transformer whose cost, size, and performance characteristics are as close as possible to the oil-filled designs but which would not be subject to destructive failures.

To develop an oilless distribution transformer, alternative methods of electrical insulation and heat transfer must be found. Responding to a typical daily cycle of power requirements, the transformer's hot spot temperature was estimated to cycle from 180°C to 300°C, with possible overload peaks to 400°C. These temperatures are greatly in excess of any acceptable limits for organic insulation; therefore, inorganic materials and designs, as well as processes to effectively use these materials, are being developed. The most promising winding design uses pancake coils (Figure 1). The most promising turn-to-turn insulation systems use glass tapes and films in combination with inorganic paints and glass frits. The most promising barrier plate and core tube insulation systems use fused silica, porcelain, and mica.

To date, about 40 transformers have been built to explore various designs and materials. The most successful of these are being continuously load-cycled. One transformer has completed over 300 load cycles and is still under test. Dielectric testing and short-circuit testing are also under way but are not as far advanced.

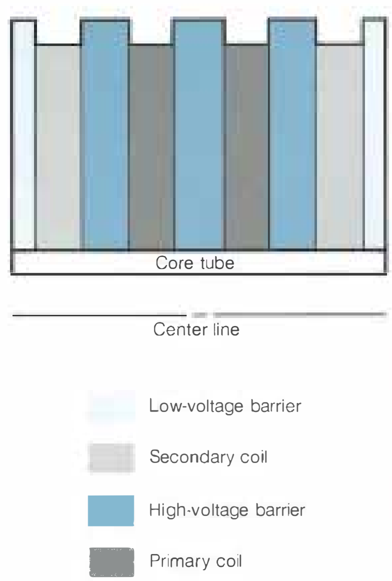


Figure 1 Pancake coil transformer winding configuration showing layered strip conductors, in contrast to the conventional concentrically wound sheet and wire conductors for distribution transformers.

The ultimate goal of this project is to produce transformers of the 25-kVA, 15-kV class to be assigned for field test on four separate utility systems. It is expected that these field trial units will be available in mid 1984. *Project Manager: Joseph Porter*

New preservatives for wood pole treatment

In 1979 EPRI initiated a project with the Institute of Wood Research at Michigan Technological University to develop improved materials and processes for treating new poles (RP1528). This research for alternative wood preservatives has ranged from basic studies of the mechanisms of decay, through biological control techniques, to the development of new biocide formulas to prevent decay. Improved and extended control of decay over present methods and materials is the major goal.

Studies of mechanisms of decay investigated both the biochemical and the chemical fungal biodeterioration pathways. The chemical processes involved in common decay were fully characterized, and it was shown that a chemical oxidation process takes place through the action of an iron salt–hydrogen peroxide system, with short-chain carboxylic acids being essential to the reaction. Although certain selected chemicals were subsequently shown to inhibit such decay, the remaining degradation that occurred was indicative of a biochemical mode of attack in parallel with the chemical mode. The rapid breakdown of wood structure by the wood fungi may be caused by the rapid biochemical diffusion away from the fungus. In other decay fungi that act more slowly, the biochemicals remain closely associated with the fungus.

Studies in the development of biological control techniques for use in wood preservation involved both fungal and termite control. Six bacterial species isolated from aged, sound, untreated wood were found to be highly active against decay fungi. Five of these were identified as exhibiting fungal inhibition by metabolite production, while the sixth showed a direct fungal breakdown action through biochemical attack. These bacteria are now undergoing field trials for the remedial treatment of internal decay in standing poles. Extensive studies of subterranean termite behavior patterns and responses to external physical and biological agents have shown that biological control of termites is feasible. Application of the antagonistic fungi appears most attractive through a bait block technique wherein the antagonistic fungi are spread through the termite colony by the termite social behavior pattern of grooming, which allows a slow-acting toxin to spread widely. Field trials using this bait block technique are now under way.

A large part of the project has centered on the development of new chemical control agents for the protection of wood products, especially new poles. One approach taken was to chemically modify the wood structure to make it inaccessible to fungal biochemical deterioration. This approach was found to be unsuitable for protection of wood in ground contact, but the dimethylol compounds evaluated were found to impart high dimensional stability to wood and are currently being evaluated in the field for the stabilization of wood panel products used in exposed situations.

The development and testing of biocides has produced several new preservative systems that exhibit excellent control of decay fungi and termites. The chemicals and/or combinations that have the greatest potential include both organic and organometallic formulas. These are currently undergoing extensive field testing, as well as evaluation for commercialization through treatment procedures and evaluation of environmental impact of the ingredients. *Project Manager: Robert Tackaberry*

Thermal overload characteristics of extruded dielectric distribution cables

Insulation characteristics of 15-kV and 35-kV extruded dielectric distribution cables (both cross-linked polyethylene and ethylene-propylene rubber insulation) are being studied to gain a better understanding of their behavior under thermal overload conditions. This work is currently in progress at Cable Technology Laboratories (CTL), with the University of Connecticut's Institute of Materials Science (IMS) as subcontractor (RP1516). The project philosophy has been reported earlier (*EPRI Journal,* September 1982, p. 47).

Earlier work demonstrated that at temperatures as high as 175°C, the physical and electrical properties of the insulation were surprisingly stable, but the currently employed shield and jacket materials were degraded. CTL is now load-cycling full-size cables to temperatures of 130°C and 145°C for periods longer than 10 months; of interest is the fact that no test cables have failed during the load-cycling procedure. At predetermined intervals, the cables are removed from the test bay and then tested by ac and impulse breakdown at the elevated temperature (a high-temperature breakdown fills a practical need but is rarely employed in conventional testing). In addition, slices of polymeric insulation have been removed from the cables and tested after the aging treatments; further, IMS has been concurrently thermally load-cycling short cable lengths (to isolate the aging-induced thermal and electrical effects), and slices from these systems are being subjected to electrical breakdown tests at CTL and physical property tests at IMS. Results to date indicate, perhaps surprisingly, excellent electrical breakdown strength characteristics for the cables and the insulation material.

At present, cables with various modified metallic shield constructions are under test. This work will be completed by the end of 1983, at which time a final report and a technical paper will be prepared for publication. *Project Manager: Bruce Bernstein*

TRANSMISSION SUBSTATIONS

Paper insulation for transformers

McGraw-Edison Co. is in the process of evaluating a series of modified kraft papers in a project designed to develop improved insulating papers for power and distribution transformers (RP1718). Improvements being sought are in the area of better thermal and dimensional stability and increased mechanical and dielectric strength (*EPRI Journal,* March 1981, p. 47).

McGraw-Edison's approach has been to screen and evaluate laboratory-prepared handsheets, and to then examine the most promising modifications by employing minicapacitor units; the latter allow the modified papers to be aged in oil under load cycle conditions, employing voltage stress and elevated temperatures.

Several modified papers surviving this treatment look quite promising, and the next step is to prepare these modified papers on a conventional paper machine at a manufacturer's facility. Riegel Products Corp., McGraw-Edison's subcontractor, performed such a trial during the second quarter of 1983.

At that point, the papers from the trial run were retested, using the minicapacitor cells, and the results were compared with the laboratory handsheets. An economic analysis is being performed and will be reported later. *Project Manager: Bruce Bernstein*

Solar flare effect on power transformers

With the recent solar flare (sunspot) activity, several utilities, particularly in the northern part of North America, have observed an increased noise level at power transformers. Geomagnetically induced dc currents were thought to be the cause, and utilities have been concerned that this might result in damage to the transformers. Of equal concern was the excess dc current flowing in the windings of converter transformers caused by less-precise firing of the valves. (Converter transformer reliability is of greater concern because of the increased interest in HVDC systems.) This project was therefore initiated to study these effects and determine if there are any harmful effects on either type of power transformer (RP1424-3).

The objectives were to assess the degree of seriousness of dc in power transformers, using both analytic and experimental methods, and to establish critical levels of combined ac and dc excitation beyond which transformer life and reliability may be impaired. An additional objective was to develop an analytic model for predicting the operating characteristics of the core when dc excitation is present.

This project successfully met all the required objectives and basically concluded that there were no deleterious effects caused by geomagnetically induced dc current in the windings. However, the noise level substantially increases with dc current, including a rich distribution of even and odd harmonics. This increased noise level may be alarming to utilities because there will be no agreement between factory noise level tests and field tests when geomagnetically induced current is present in the unit.

The analytic model developed showed good correlation with the experimental model and can be used by manufacturers and utilities together to analyze any particular transformer design where a concern exists. However, from the results of this project, there seems to be little likelihood of harmful effects as the result of geomagnetically induced currents. *Project Manager: Edward Norton*

HVDC circuit breakers

There are many potential opportunities for the application of HVDC breakers in two-terminal, multiterminal, and proposed unconventional dc systems, some of which were explored by Bonneville Power Administration at the March 1983 Symposium on HVDC Technology in Rio de Janeiro. R&D on various concepts of HVDC circuit breakers has been carried on in the United States, Europe, Japan, and Russia for two decades; however, no equipment that can be termed a full-voltage HVDC breaker is yet in service.

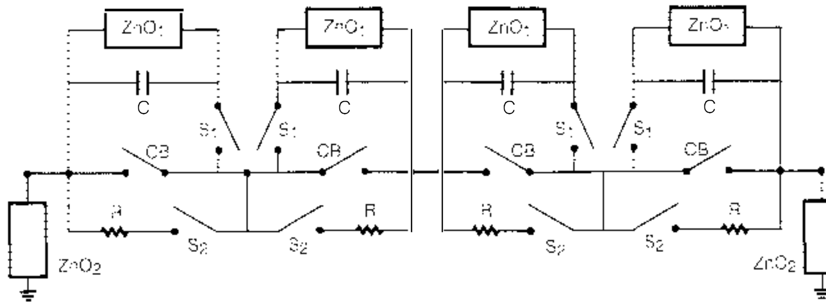
The purpose of an EPRI project is to develop and construct two promising breaker concepts and conduct full-scale field tests to determine their performance (RP1507). Bonneville Power Administration, with funding support from DOE's Electric Energy Systems Division, has joined with EPRI to accomplish this development. The Los Angeles Department of Water & Power is aiding in the test planning and execution. Tests are planned for late 1983 at the Celilo Station of the HVDC Pacific Intertie.

The fundamental principle of operation for ac circuit breakers is to part the contacts during the ac current cycle and arc until a natural current zero occurs, then rapidly establish the breaker's dielectric strength, thus interrupting the circuit. Because dc circuits have no naturally occurring current zeros, a dc breaker must force the current to zero by creating a counter voltage in excess of the driving voltage and then rapidly establish its dielectric strength. During this process the breaker must also absorb a significant amount of energy that is stored in, and supplied by, the system.

The dc breakers being developed under this research project should consist of standard components as much as possible and be modular in construction so as to reduce their costs and increase their application flexibility. They are to be single-pole with full voltage capability for a ±500-kV system. The maximum counter voltage is 700 kV; the maximum energy absorption is 10 MJ; and the continuous and interrupting current is 2.2 kA.

The circuit diagram for the dc breaker being developed by Westinghouse (RP1507-2) consists of four identical series-connected modules (Figure 2). In operation, the SF_6 puffer breaker contacts (CB) are opened and develop a modest arc voltage. Switches S_1

Figure 2 Circuit diagram of Westinghouse Electric Corp. 500-kV circuit breaker. In operation, when the SF_6 puffer breaker contacts (CB) open, the switches (S_1) close, thereby charging the capacitors (C); when each is charged to 175 kV (700 kV total), the zinc oxide arresters (ZnO_1 and ZnO_2) conduct to absorb the remaining energy in the system, and the circuit is isolated.



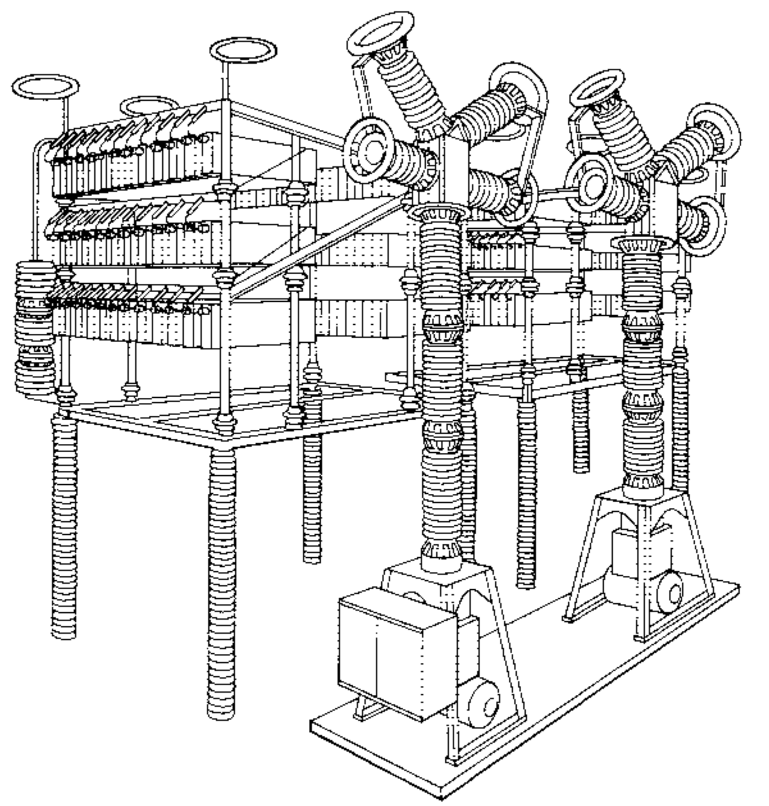


Figure 3 Conceptual drawing of the Westinghouse prototype 500-kV HVDC breaker.

then close to insert the uncharged capacitors, C. The current is then diverted into C, and the capacitor voltages rise very rapidly. When the voltage across each of the four modules reaches 175 kV (700 kV total), zinc oxide arresters conduct to limit any further voltage rise and to absorb the system energy. When the energy has been absorbed, each arrester ceases to conduct, and the circuit is isolated. The breaker is equipped with closing resistors (R) and separate switches (S_2) to limit transients during closing. Figure 3 shows a conceptual view of the breaker elements.

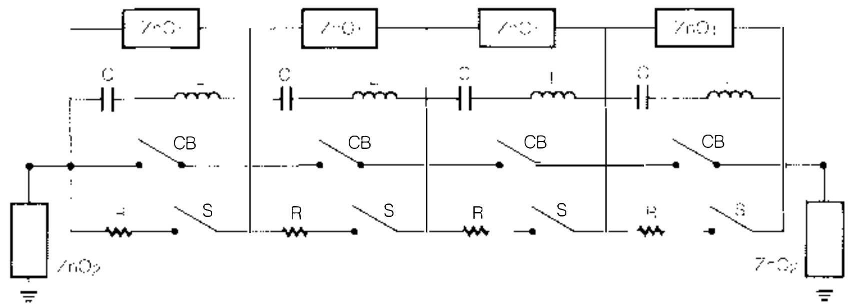
The circuit diagram for the dc breaker being developed by Brown Boveri Corp. (RP1507-3) is shown in Figure 4. It also consists of four identical series modules. In operation, the air blast breaker contacts (CB) open, thus activating the commutating circuit L and C. The loops formed by the breaker contact arcs and L and C exhibit dynamic instability because of the negative arc voltage of the circuit breaker arcs. A current oscillation increases in each loop until its magnitude is equal to and of opposite polarity to the current to be interrupted. At that point the air blast breaker interrupts, thus transferring the current to the commutating circuit. The voltage across each module then increases rapidly until it reaches 175 kV (a total of 700 kV). The zinc oxide arrester then conducts, and subsequent events are as described in the previous paragraph. This breaker is also equipped with closing resistors (R) and a resistor switch (S). Figure 5 is a conceptual view of the major elements.

Plans are to have the circuit breakers delivered to the test site by August 10, 1983. The initial test series will be conducted at the present HVDC Pacific Intertie voltage of 400 kV. A second series of tests is being planned at 500 kV after the intertie is upgraded. It should be noted that the maximum circuit breaker counter voltage in each test is 700 kV. The chief difference in the two test series is expected to be in the energy absorbed in the breaker zinc oxide arrester (Figures 3 and 5). *Project Manager: Joseph Porter*

Dc energy metering device

Dc energy metering is a forgotten art that we are about to relearn. High-voltage dc (HVDC) systems are being used more and more for power transmission. So far, all the energy metering has been handled on the ac side of the HVDC converters. Although this is a workable approach, there could be significant errors in the measurement if the energy exchange at a point on the dc side is inferred

Figure 4 Circuit diagram of Brown Boveri Corp. 500-kV HVDC circuit breaker. When the air blast breaker contacts (CB) open, an oscillating current flows in each of the four loops consisting of the L, C, and breaker arc. The oscillating current grows in magnitude until it is equal to and of opposite polarity to the current to be interrupted. The current is commutated into the L and C circuit alone, where the voltage builds rapidly to a total of 700 kV across the four modules in series, causing the zinc oxide arresters (ZnO_1 and ZnO_2) to conduct. They absorb the remaining energy in the system, and the circuit is isolated.



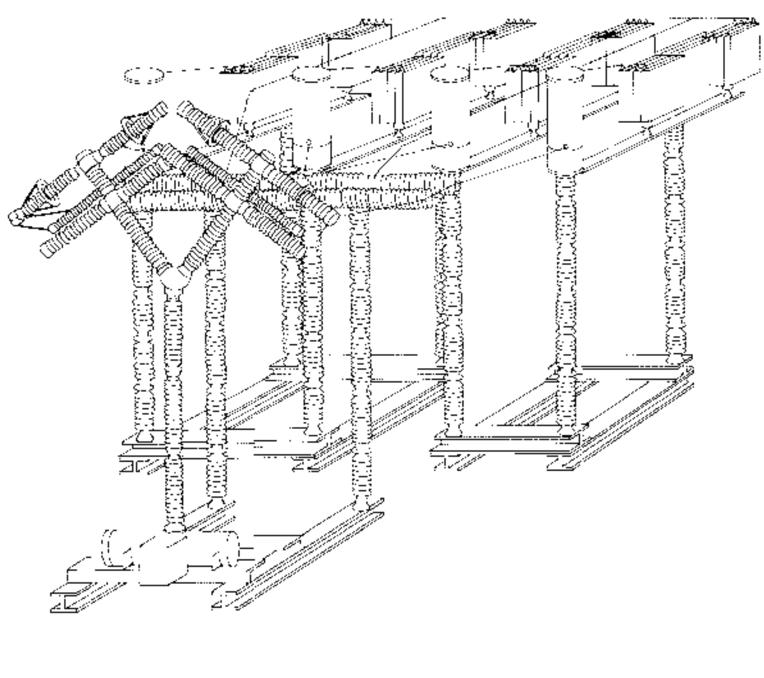


Figure 5 Conceptual drawing of the Brown Boveri Corp. prototype 500-kV HVDC breaker; it employs air blast breakers instead of SF_6 puffer breakers, as on the Westinghouse unit, and an L–C circuit for commutation instead of switched capacitors. The breakers are comparable in size.

from the ac readings. EPRI therefore sponsored development of a dc revenue meter at Washington State University (RP1510).

The developed dc revenue meter is a digital, microprocessor-based device that has been built to accommodate a variety of input sources.

- Resistive voltage divider for measuring the pole-to-ground voltages from both poles of a bipolar HVDC system
- Current-measuring transductor for both poles for direct current measurements
- Two inputs from an electronic current transducer (developed under RP668) for accurate measurement of the direct current in one of the two poles.

This meter has been installed for testing at Los Angeles Department of Water & Power's Sylmar Converter Station, the southern terminal of the HVDC Pacific Intertie.

The major design challenge has been to meet the allowable error tolerance for a metering device; because there is no established standard for dc energy metering devices, ac standards were used as a guide.

Measurement errors are introduced into all parts of a measuring system, and the primary measuring devices also have errors. In this case, neither the voltage dividers nor the current-measuring transductors have metering accuracy. However, if the errors are predictable, a computer can be used to compensate for the errors. The voltage dividers are assumed to be fairly stable. By knowing the divider ratio, a ratio error correction can be included in the program. The transductors are stable but nonlinear. However, by using a linear correction function it is possible to significantly improve the accuracy of the transductor current measurements. Although it was not attempted in this design, it is also possible to correct for errors in signal conditioning and analog-to-digital (A–D) converter circuits. The simplest correction normally consists of a gain and offset correction.

Two errors that are unique to digital systems arise from a limited resolution of A–D converters and from arithmetic operations within a digital processor. The accuracy of an individual sample from an A–D converter cannot in theory be better than ± 0.5 of the least significant bit; hence; a minimum number of bits are required for the A–D converter. However, it turns out that a small amount of white noise in the measured quantity, combined with sample-averaging techniques, makes it possible to achieve an accuracy that is better than one-half of the least significant bit. Hence, A–D converter resolution is not a significant problem. Processing errors can be controlled by using a sufficient number of bytes (1 byte equals 8 bits in binary form) for the arithmetic operations.

Verification of the design is another problem area. It is necessary to have an accurate reference for verification of the device's accuracy, and this can only be done in the laboratory environment. Because there is no reference available for verification of the device's performance in the field, a field trial was set up to allow comparison between energy measured at the ac side of an HVDC converter and at the dc side of the same converter. The difference between the ac and dc readings is a combination of energy losses in the converter and measuring errors in the two metering devices. The converter losses have been estimated, although the accuracy of the estimate is relatively uncertain.

About a year's worth of data has been accumulated from the field trial, and the data analysis is almost complete. The results from a two-week period are illustrated in Figure 6. As can be seen, there is a remarkably small difference between the dc readings and the ac readings that were compensated by the estimated converter losses. There appears to be a bias of about 0.03% for the Pole A readings and about 0.5% for the Pole B readings. The Pole A measurement relied on an accurate electronic current transducer input, whereas the Pole B readings relied on the less-accurate current-measuring transductor. However, with the bias removed, even the Pole B measurements would be quite acceptable. The small differences also give some confidence in the converter loss estimates; this by itself is a valuable indication because converter losses cannot be directly measured either in laboratories or in the field. The total energy flow during the period was about 200,000 MWh. The accumulated difference for the 13 days was about 0.03% for Pole A and about 0.5% for Pole B. These estimates were made without trying to eliminate the measuring biases. It is, of course, impossible to say which one of the readings is correct. However, the close

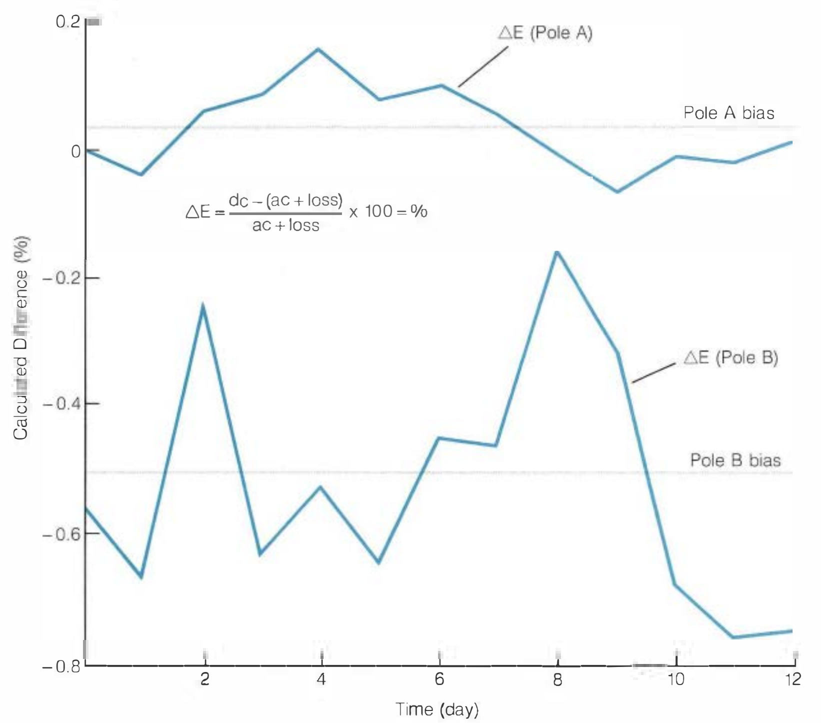


Figure 6 Calculated difference (ΔE) between the daily energy measurements on the ac and dc sides of an HVDC converter. The ac measurements have been compensated by estimated converter power losses. Power flow is from the dc to the ac side.

correlation between the ac and the dc readings does give some confidence in the new dc revenue metering device. A gross error in the device should have been apparent. The design is proved and the project completed. The final report will be published later this year. *Project Manager: Stig Nilsson*

POWER SYSTEM PLANNING AND OPERATIONS

Power plant performance

The objective of this project is improvement in power plant heat rate, plant availability, and system economic dispatch. An advanced, computer-based plant performance instrumentation system will be developed for prototype installation in an existing fossil fuel plant of Potomac Electric Power Co. (Pepco), which has been selected as the host utility. Morgantown Unit 2, a 575-MW, supercritical unit will be used as a demonstration facility. This system will be designed and developed to provide continuous detailed analysis of the unit performance to a utility's plant engineering, plant operations, power supply group, and system control center. For example, the development of this prototype system will provide the utilities with information on those additional devices and procedures that were selected/developed, tested, and found to be of substantial benefit.

Pepco is the prime contractor and host utility. Subcontractors include Power Technologies, Inc., Lehigh University, and Combustion Engineering, Inc. The project is jointly sponsored by two EPRI divisions: Coal Combustion Systems (RP1681) and Electrical Systems (RP2153). A companion article describing RP1681 appears in the Coal Combustion Systems Division report in this issue.

Areas of investigation for the Electrical Systems Division include incremental heat rate analysis, control system dead bands, power system performance indexes, unit commitment procedures, effects on system scheduling of plant component outages, and improved plant/control center data communications.

The following are being considered for inclusion in the instrumentation system.

- New/improved instruments and sensors for measuring air, steam, water, and gas flows, pressures, temperatures, and electrical parameters
- Microprocessor hardware and software
- Expanded power plant computer processing capabilities
- Capabilities for recording historical performance of all equipment
- Expanded, automated analysis of plant and system performance
- Maintenance and tuning of the individual power plant components, including instrumentation
- Revised operating procedures at both the power plant and the system control center levels
- Enhanced or alternative testing procedures to provide performance data on a more accurate and timely basis

The prototype instrumentation system will be capable of continuously determining both static and dynamic plant performance to enhance heat rate and system dispatch; testing and evaluating new operator/control procedures; evaluating new instrumentation, testing procedures, and performance control/analysis algorithms for improving heat rate; and comparing computer results with actual measurements and plant responses to validate the analyses made during this project.

This phase of the project will continue through December 1985, with annual reports to the industry. *Project Manager: John Lamont*

Static security analysis and demonstration

It has been 14 years since the first digital computer–based system control center was installed by the Michigan Electric Power Co. As computer hardware costs have decreased, more control and monitoring functions have been added to the list of application programs being used on this and other control center computers to assist the power system operator in day-to-day operations.

An application program is being developed to assist the operator in preserving the power system's security by preventing interruptions of customer loads (RP1712). This program will allow the operator to study the steady-state conditions that might result from a variety of sudden changes in generation, transmission, or loads, based on contingency analysis. The program also develops the actions an operator can take for each of the most likely system disturbances. (This capability is called security enhancement.) The term *static security analysis* refers to the effective integration of contingency analysis and security enhancement into a tool for daily use by the operator.

The project had five major objectives, and the work was divided into two phases. The Phase 1 objectives were the following.

- Perform R&D on contingency analysis and security enhancement, focusing work on methods that meet the accuracy and rapid calculation requirements for on-line static security analysis
- Develop research-grade computer programs for static security analysis and evaluate their capabilities to meet on-line requirements
- Select a host utility in whose control center the static security analysis programs will be installed, tested, demonstrated, and evaluated

Phase 2 had the following objectives.

- Develop the integrated static security analysis capability, using preproduction-grade programs
- Install, test, demonstrate, and evaluate the static security analysis programs in the host utility control center

The work on Phase 1 lasted 20 months and has been completed. Boeing Computer Services, Inc., was the prime contractor, assisted by ESCA Corp., a subcontractor, and two consultants, William F. Tinney and Brian Stott.

During Phase 1, computer programs for a faster, more reliable security analysis capability were developed and tested. In addition, the methods to be used in security enhancement were developed. The effects of the control actions that an operator has at his disposal were studied. These controls not only affect real power flow on transmission lines but the voltages at the ends of the lines (buses) and the phase angle differences between buses. A common basis for comparing the control actions was found to be their costs. The security enhancement programs that were developed and tested identify which controls an operator should use, how much change in control is required, and the incremental operating cost for each because of the most likely system disturbances. The host utility in the demonstration is Wisconsin Electric Power Co. (Wepco).

The work of Phase 2 has been under way since June of 1982 for this 32-month contract with ESCA Corp. as the prime contractor. Assisting ESCA will be Wepco and the two consultants who participated in Phase 1.

Currently, the detailed functional design specifications for the integrated contingency analysis and security analysis capabilities are being developed. These specifications are needed to transform the research-grade programs from Phase 1 into an operator-oriented tool that can be used in daily monitoring and control of system security. Two seminars to demonstrate the capabilities developed in this project are planned for the fourth quarter of 1984. *Project Manager: Charles J. Frank*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

LONG-RANGE ATMOSPHERIC TRACER STUDIES

It is a fairly new idea that air pollutants emitted from such conventional earth-bound sources as power plants can travel long distances and significantly affect air quality at points far from the source. The global dispersion of debris from the atmospheric testing of nuclear weapons represents quite a different situation. Although such dispersion has shown that long-range transport is possible, it involves stratospheric injections and long residence times. In contrast, pollutants from conventional sources are emitted into the lower atmosphere, where they are affected by highly variable and sometimes convergent wind fields, deposition losses, and variable chemical transformation rates. All these factors immensely complicate the quantitative evaluation of long-range transport in the lower atmosphere. To help answer the difficult questions about such transport, EPRI is conducting studies that use inert tracer gases to map air mass movement.

Although the concept of long-range air pollutant transport is well understood and widely used in a qualitative sense, there is no generally accepted quantitative definition. It is well known that for each pound of pollutant gas emitted, a few molecules will circumnavigate the globe several times, whereas other molecules will be deposited within minutes; the range of possible transport distance is enormous. Further, any quantitative assessment of the problem of long-range pollutant transport requires more than a determination of residence time and distance traveled. Operationally, the most useful criteria are the relative contribution of air pollutants emitted in one area to air quality impairment in another area and the frequency with which pollutants from a given source area affect air quality in another area.

EPRI's eastern and western regional air quality studies (ERAQS, WRAQS; RP1630) have adopted these criteria in designating the research required for reliable source-attribution estimates for any particular regional air quality problem. Two research approaches are being pursued in parallel. One involves large-scale experimental releases of inert tracer gases to track plume trajectories and gas dilution rates. The other seeks to develop improved regional air quality models by using the data generated in the Sulfate Regional Experiment (SURE; RP862), as well as precipitation chemistry data from ERAQS, the utility acid precipitation study (RPU101), and the DOE–EPA precipitation-monitoring network (MAP3S). In their present stage of development, regional air quality models are not precise enough to estimate the contribution of emissions in one source area to air quality impairment in another area. However, continued research and additional inputs of experimental data should lead to better models.

Because of the need for more detailed information about the long-range transport and dilution of pollutants, EPRI's current emphasis is on large-scale field experiments. (This approach also has the advantage of providing, in a relatively short period of time, information that is important for assessing proposed emissions control scenarios.) The development of perfluorocarbon tracer technology has added a new dimension to such field experiments. Now inert tracer materials are available that can be tracked for more than 1000 km from their release point. These tracers make it possible to measure directly the trajectories of plumes and the minimum dilution of gases due to atmospheric mixing. Together with high-resolution measurements of reactive pollutant gases, the tracer data will facilitate the quantification of long-range pollutant transport and associated air quality effects.

What we know now

Although current information provides only qualitative descriptions of long-range transport, it is very helpful in defining the dimensions of the problem and in guiding more quantitative research. Two EPRI projects are particularly useful in this regard.

The first is the North Sea transport and cloud chemistry project, jointly funded by the UK Central Electricity Generating Board and EPRI (RP1311). In this project inert tracers were injected into a power plant stack in England and then tracked by aircraft as they moved over the North Sea toward Norway. On one occasion the tracer plume was clearly discernible at 700 km from the source, but generally the range of detectability was less than 500 km. Because this project took a case study approach, generalizations about the frequency of long-range transport are not possible. However, the data do confirm that under certain meteorologic conditions, plumes can travel long distances.

The second project is SURE, which provided exhaustive information on the distribution of sulfur dioxide (SO_2) and suspended particulate sulfates ($SO_4^{=}$) in the eastern United States over a 17-month period in 1977–1978. (Also, in connection with ERAQS, air quality and precipitation chemistry data were collected at the nine SURE Class I stations for another year.) Although these data do not define long-range transport per se, they provide compelling evidence that patterns of wet sulfate deposition and atmospheric sulfate concentrations are geographically associated with major SO_2 source areas (Figures 1 and 2).

Figure 1 Data collected during SURE reveal the geographic coincidence of major SO_2 source areas (shaded boxes, showing SO_2 emissions in t/d) and the wet deposition of sulfates (isopleths, showing annual deposition in mg/m^2).

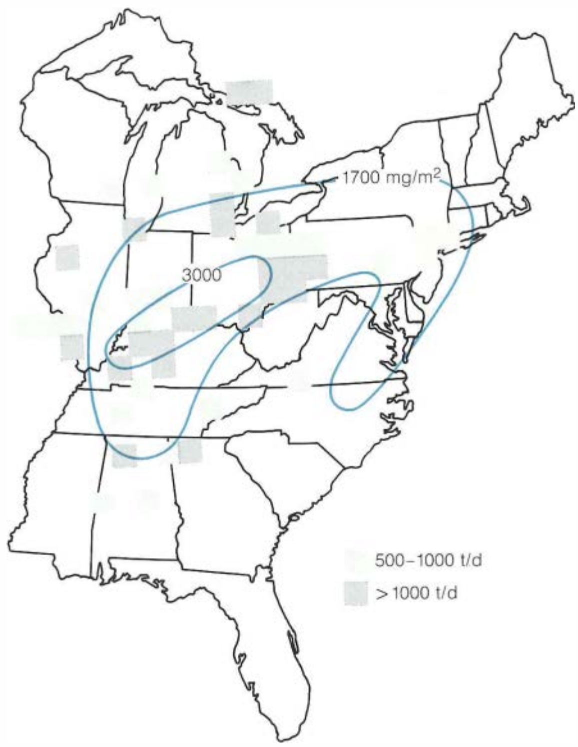


Figure 2 Geographic coincidence of major SO_2 source areas (shaded boxes, showing emissions in t/d) and maximum suspended particulate sulfate concentrations during SURE. The isopleths map the 24-hour average sulfate concentrations ($\mu g/m^3$) that were exceeded 10% of the time, or 36 days a year.

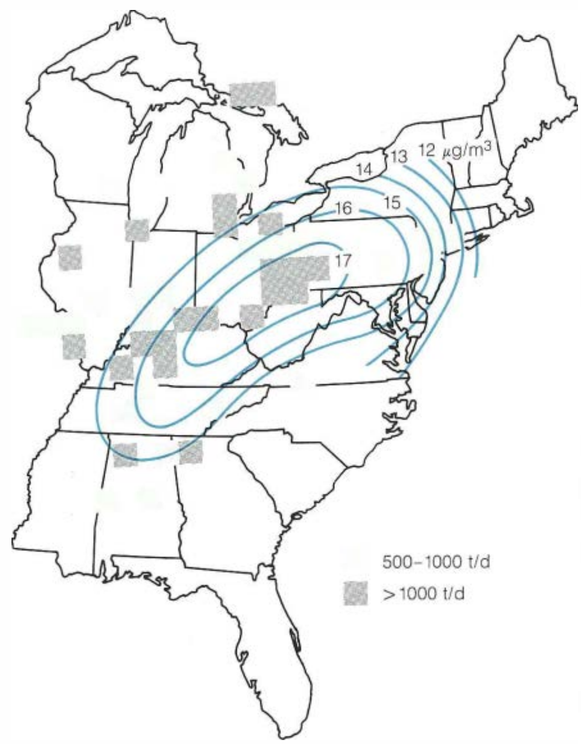


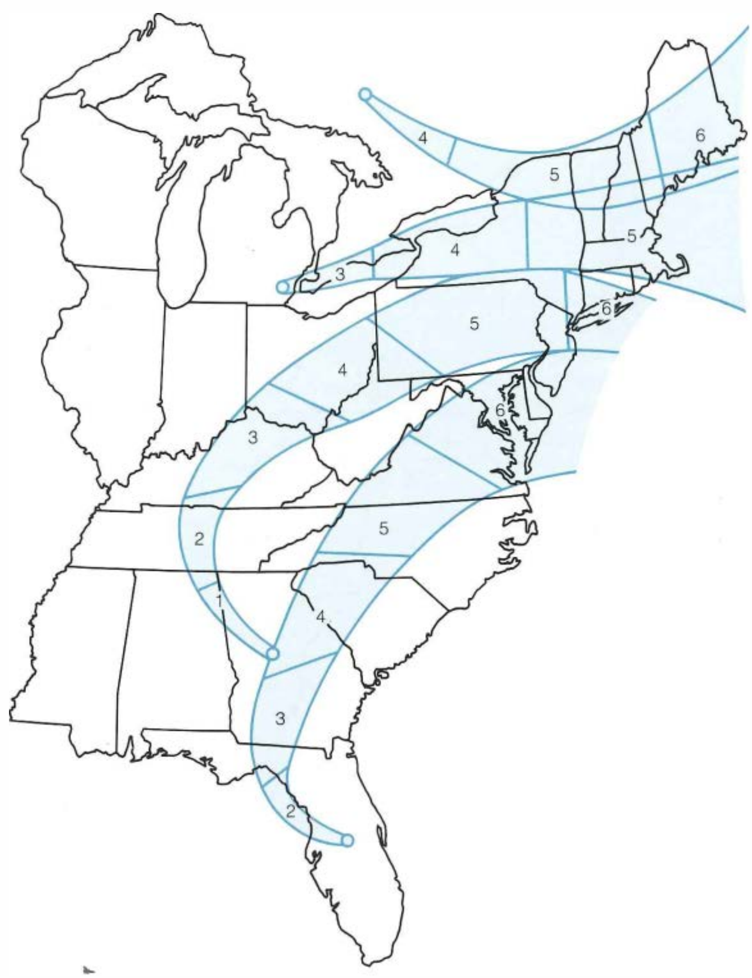
Figure 1 shows that the maximum deposition of sulfates in precipitation coincides with the major SO_2 source areas; the deposition declines markedly at distances of 200–300 km from the source areas. Figure 2 shows the pattern of suspended particulate sulfate concentrations that were exceeded 10% of the time in the SURE region. These data enable an examination of the source-receptor relationship during episodes when meteorologic conditions were such as to maximize sulfate formation and accumulation. Again, the geographic association between the highest sulfate values and the major SO_2 source areas is unmistakable. (Note the rapid decrease in sulfate concentrations as one goes from central Pennsylvania and New York state into New England.) A statistical analysis of these paired datasets suggests that the zone of influence of SO_2 sources on sulfate concentrations is generally 200–300 km. However, individual case studies show that the distance may exceed 500 km on relatively rare occasions, a result in keeping with the less extensive North Sea measurements.

Long-range tracer experiments

As indicated by the above summary, empirical data on long-range pollutant transport are needed for evaluating alternative emissions control scenarios. The development of perfluorocarbon tracer technology permits quantitative assessments of long-range transport that were not possible a few years ago. However, even with improved experimental capabilities, there are still questions about the design and execution of measurement programs that must be addressed before a massive field experiment can be mounted. EPRI is conducting a step-by-step assessment of the feasibility of such an experiment, with the ultimate objective of developing a comprehensive experimental design (RP2434). Although the SURE project provides a sound base for this effort, the complexities and data requirements of the tracer experiment go well beyond those of SURE.

According to the initial design concept, the experiment (designated the massive aerometric tracer experiment, or MATEX) would involve the sequential release of inert tracer gases from various emission source areas in the eastern United States and south-

Figure 3 EPRI is designing a large-scale experiment in which inert tracer gases will be released sequentially at various points in the eastern United States and southeastern Canada and monitored daily by surface stations and aircraft. Shown here is a projected series of four releases and plume trajectories; the numbers in the trajectory segments indicate the number of days since the first release in the series.



eastern Canada (Figure 3). A surface network of 600 sampling stations and a fleet of at least eight long-range aircraft would be used to track the tracers on a daily basis. These measurements would provide a detailed history of air mass movement and an estimate of the minimum gas dilution caused by atmospheric mixing. Approximately 100 aerometric and precipitation chemistry stations would be located in the experimental area, and the aircraft would be instrumented for chemical measurements. Continuous operation of the experimental network for at least one year is contemplated. Close cooperation with U.S. and Canadian federal research agencies has been, and will continue to be, an integral part of EPRI's research efforts in this area.

While the MATEX concepts are being investigated in detailed feasibility and design studies, EPRI is participating in a preliminary tracer experiment called CAPTEX 83 (cross-Appalachian tracer experiment; RP2370). In this project—which is jointly sponsored by EPA, DOE, the National Oceanic and Atmospheric Administration, EPRI, and the Canadian Atmospheric Environment Service—perfluorocarbon tracers will be released from sites in Ohio and Ontario. The movement of the gases over the northeastern United States and southeastern Canada will be tracked by 80 surface samplers, 20 upper-air sounding stations, and up to four aircraft. Because only six tracer releases are planned for CAPTEX 83, a long-term assessment of long-range transport will not be possible. However, CAPTEX 83 is expected to provide invaluable guidance for the design of the more comprehensive MATEX research, and its data will be useful in developing and evaluating regional air quality models.

Although long-range transport is a key factor in regional air quality, other aspects of the problem require improved understanding as well. Two important examples are in-cloud chemistry and the dry deposition of gases and particles. As part of its fundamental long-term research program, EPRI is sponsoring theoretical, laboratory, and specialized field studies in these and other areas (RP1369, RP1434, RP2023, RP2264). The intent of this integrated research is to provide the most reliable and complete information possible on the regional behavior of multiple pollutants from multiple sources. An improved understanding based on this information is essential to rational management of regional air quality problems. *Program Manager: Glenn R. Hilst*

UNIT TRAIN COAL TRANSPORTATION COSTS

The use of unit trains for hauling coal is increasing at a rapid rate. As a result, a better understanding of the operating and maintenance costs of coal unit trains is necessary for evaluating alternative sources of coal and for rate and contract negotiations. Also, in order to identify effective ways of controlling the cost of transporting coal in unit trains—for example, new equipment technologies and improved operating and maintenance methods—it is essential to understand the physical phenomena that generate costs. To meet these needs, the Energy Resources Program of EPRI's Energy Analysis and Environment Division undertook an investigation of costs for coal unit trains, with Arthur D. Little, Inc., as the contractor (RP1983).

The unit train study has focused on those major elements of operating and maintenance costs that are poorly understood or controversial. The following topics were covered: maintenance-of-way costs, fuel consumption, car maintenance costs, alternative sources of car maintenance, and technical and economic aspects of the use of aluminum cars.

To gather information the contractor has conducted a thorough literature review, a survey of several cooperating utilities, and site visits to the facilities of utilities, railroads, contract maintenance shops, and equipment manufacturers. Utilities that have provided significant assistance include Delmarva Power & Light Co. (Delaware); Detroit Edison Co.; Pennsylvania Power & Light Co.; Potomac Electric Power Co.; San Antonio City Public Service Board; System Fuels of Middle South Utilities, Inc.; and Wisconsin Public Service Corp.

Maintenance-of-way costs

Several interesting and significant findings have emerged from the study. In the area of maintenance-of-way costs, for example, it was found that rail life may be substantially reduced by coal unit trains with 100-ton cars (in comparison with trains carrying mixed freight) because of the higher levels of stress caused by the higher axle loads. Empirical observations of rail life from many railroads around the world, together with the results of analytic modeling, suggest that rail life reductions of up to 35% may occur under coal unit trains. However, a comparison of total estimated maintenance-of-way costs indicates that the cost per gross ton-mile of coal unit train traffic will generally be no more than 7% higher than the cost per gross ton-mile of mixed freight (Table 1), and may in fact be lower under certain circumstances. Although the variable maintenance-of-way costs are estimated to be higher for coal unit trains, most of this increase is offset by a projected decrease in fixed costs and yard track maintenance costs—a fact that must be taken into account in rate negotiation.

The exact change in maintenance-of-way costs for a given situation depends on a wide range of factors. These factors vary from one route to another, and some are hard to quantify. The study investigated the factors, as well as the best available methods for quantifying their effects on costs. It has been found that an increase in any of the following factors causes maintenance-of-way costs per gross ton-mile to decrease.

- Traffic density
- Rail weight, quality, and hardness
- Ballast quality, thickness, and width
- Regularity of scheduled maintenance
- Labor productivity
- Quality of drainage
- Track occupancy time

(Track occupancy time refers to the length of time that a track is continuously available for maintenance. The longer these periods, the more efficient maintenance is, because less time is spent in setting up and dismantling equipment.)

In contrast, an increase in any of the following factors causes maintenance-of-way costs per gross ton-mile to increase.

- Axle loads, especially over 28 tons
- Speed, especially over 40 mph (64 km/h) for 100-ton cars
- Curvature
- Gradient
- Rain or snow
- Temperature extremes
- Tie spacing
- Frequency of unstable cars
- Imbalanced operation on curves

Another of the study's significant observations concerns the so-called harmonic loading effect of unit trains. Some researchers have hypothesized that because all axles are identical in a unit train, the loads they exert on the track are also identical; thus every axle would exert a high load on the same points in the track, causing accelerated fatigue and wear at those points. In contrast, the hypothesis continues, with trains hauling mixed freight high loads are distributed more uniformly along the track because each axle behaves differently. It was concluded that while this effect may exist, there are no field data available to prove that it does, much less any information on its magnitude. This finding suggests that until additional data come to light on the harmonic loading effect, any increase in maintenance-of-way costs attributed to high axle loads ought to be distributed among all 100-ton cars, not just those in unit trains and certainly not just those in coal unit trains. (A growing proportion of all rail traffic moves in 100-ton cars.)

Table 1
MAINTENANCE-OF-WAY COSTS
(1980 ¢/1000 gross ton-miles)

	Trains With Mixed Freight	Coal Unit Trains
Fixed costs		
Ties	15.28	14.00
Other	97.89	86.83
Total	113.17	100.83
Variable costs		
Rail	42.67	62.22
Ties	12.81	13.06
Other	88.62	98.34
Total	144.10	173.62
Grand total	257.27	274.45

Note: Average costs are given for the mixed-freight trains and upper bound costs for the coal unit trains.

Fuel consumption

The EPRI study indicates that conventional methods of estimating fuel use for coal unit trains, which are based on extrapolations from fuel consumption in trains carrying mixed freight, tend to overestimate consumption. One reason for this overestimation is that unit trains operate at more uniform speeds, which reduces fuel consumption. Another reason is that the conventional estimation methods take into account fuel used in a variety of activities (e.g., yard operation) that support only non-unit-train traffic. Also, the horsepower-to-ton ratios for unit trains are usually lower than the ratios for trains carrying mixed freight; this leads to a further reduction in fuel consumption.

Approximate methods for estimating the fuel consumption of unit trains in mainline operation have been developed. For example, a computer model validated with data from field tests has been used to simulate fuel consumption for operation over different types of terrain. Sensitivity studies have also been conducted that show the importance of various factors to fuel consumption, including curvature, gradient, operating speed, train length, car weight, and starts and stops. The analysis shows the importance of steady train operation in controlling fuel use. A single unscheduled stop for a train weighing 14,000 gross tons and operating at 40 mph (64 km/h) can increase fuel consumption by as much as 40 gal (151 L).

Car maintenance

The study suggests that the costs of maintaining cars for coal unit trains are markedly lower than the costs of maintaining cars used in mixed-freight transport. The components that contribute most to cost have been identified and their expected life esti-

Table 2
ESTIMATED ANNUAL CAR MAINTENANCE COSTS UNDER ADVERSE CONDITIONS
(1982 $)

Component	Base Cost*	Severe Terrain	Freezing/Wet Climate	Harsh Loading and Unloading Methods	Bad Track and Train Handling
Wheels and axles	610	1525	671	610	732
Bearings	173	208	190	190	173
Brake shoes	58	145	70	58	87
Couplers	64	128	64	109	77
Center plates	27	68	27	32	32
Car body	72	72	108	108	86
Springs	68	102	68	82	102
Draft gear	78	177	86	94	94
Total	1150	2425	1284	1283	1383

*Lower bound cost, Association of American Railroads data for 50,000 mi/yr.

Table 3
EFFECTS ON COAL TRANSPORTATION COSTS OF REPLACING STEEL CARS WITH ALUMINUM CARS

Cost Element	Estimated Effect on Cost*
Fuel cost	About 12% lower
Maintenance-of-way cost	About 12% lower
Crew cost	As much as 9% lower
Locomotive maintenance cost	As much as 9% lower
Locomotive capital cost (for a fleet)	As much as 9% lower
Car maintenance cost	About 9% lower
Car capital cost (for a fleet)	30–40% higher
Accident cost	About 30% higher

*Assumes that an empty aluminum car weighs 20 tons.

mated. The effects of key environmental variables on the annual maintenance costs of these components have also been assessed. For example, it was estimated that severe terrain (i.e., high gradients and curvatures) may increase the annual costs related to wheels and axles by a factor of 2.5. Similarly, high-sulfur coal can cause accelerated corrosion of steel car bodies, increasing annual body repair costs by a factor of up to 1.2. The set of cost factors developed in the study can be used to estimate annual maintenance costs for cars operating in different environments (Table 2). Compared with average conditions, for example, severe terrain can cause annual car maintenance costs to double.

An evaluation of the three major sources of car maintenance—railroad shops, contract shops, and utility-owned shops—has been conducted in both financial and nonfinancial terms. The results of the nonfinancial analysis suggest that, in general, there are strong reasons for utilities to have their own car maintenance shops. In a survey of utilities, for example, car out-of-service time, quality of work, data base development, and ease of cost auditing were cited as reasons for preferring utility shops. (Such an assessment will vary, of course, depending on the circumstances of an individual utility and the location and quality of the railroad and contract shops it has access to.) The results of the financial analysis, on the other hand, suggest that a utility-owned shop is justified only for utilities with a fleet of 1000–1500 cars or more. Exceptions are small shops with low capitalization that can do simple repairs more cheaply than an outside shop.

Aluminum cars

Aluminum cars show significant potential for reducing the cost of transporting coal in unit trains, primarily because they may weigh as much as 35% less than conventional steel cars when empty. The lower empty weight and the resulting higher coal-carrying capacity (for the same gross weight of the car) lead to a decrease in many cost elements (Table 3). However, the study suggests that there are several critical factors that ought to be considered by a utility proposing to buy aluminum cars. Among these are the design details, which can determine a car's tendency to have early and repeated fatigue failures; the purchase price; the freight rate discount offered by the railroad for coal carried in aluminum as opposed to steel cars; and maintenance costs, measured in terms of both direct costs and car out-of-service time. Given a well-designed car, a purchase price not more than 50% above that of a steel car, a freight rate about 5% per ton lower than the rate for steel cars, and maintenance costs similar to those of steel cars, the aluminum car appears to be a good investment—offering an internal rate of return on the incremental investment (over the steel cars) of around 40%. The study identified methods for increasing the likelihood that such a rate of return will actually be achieved. The analysis indicates that the rate of return is quite sensitive to the freight rate discount, car out-of-service time, and maintenance costs. Thus a cautious evaluation of these factors is desirable before making a major investment in aluminum cars. *Project Manager: Edward Altouney*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

ADVANCED FUEL CELL TECHNOLOGY

The major objective of EPRI's fuel cell research program is the introduction of first-generation phosphoric acid fuel cell power plants with a heat rate of 8000 Btu/kWh into utility use. These power plants will be able to use any clean fuel capable of being reformed to a hydrogen–carbon dioxide–carbon monoxide mixture, such as natural gas, light-distillate hydrocarbons, and alcohol. The objectives of the advanced fuel cell technology subprogram are to improve the above heat rate for acid fuel cells still further and to develop alternative systems, such as the molten carbonate fuel cell, that offer more fuel flexibility and still lower heat rates than advanced acid fuel cells. (The most recent Journal *report was in the September 1982 issue, p. 56.)*

At the present time the EPRI advanced fuel cell technology subprogram has three project groups.

- Development of new materials for the acid fuel cell cathode (air electrode) and its associated structures (current collectors, cell separator plates), as well as an understanding of the causes of the comparatively poor performance of the phosphoric acid fuel cell cathode (RP1200)
- Synthesis and testing of stable acid electrolytes (either in pure form or as an additive to phosphoric acid) that may result in greater performance than pure phosphoric acid (RP1676), as well as a limited investigation of solid oxide electrolytes
- Investigation of the molten carbonate fuel cell for application either as an internal-reforming, methane-fueled power plant, projecting heat rates near 6000 Btu/kWh, or integrated with a coal gasifier and bottoming cycle, projecting an overall power plant heat rate of 6800 Btu/kWh (RP1085, RP2344, and RP1041)

New materials for the acid fuel cell cathode

Higher fuel cell performance (power output and efficiency) may require greater cell operating temperatures and pressures. Although acetylene-black supports for the platinum or platinum alloy cathode catalyst are adequate at 205°C, 8 atm (811 kPa), and 0.73 V per cell, they are probably not suitable for use at the higher cell temperatures and consequent higher cell voltages required for lower system heat rates. In 1982 carbides and silicides were examined as possible candidates for high-stability conducting catalyst supports. The most satisfactory of these materials to date has proved to be titanium carbide (RP1200-8). During the past few months, this material has been successfully prepared in a high-surface-area form equivalent to acetylene black in terms of m^2 per unit volume (Figure 1). It has recently been successfully catalyzed with high-surface-area platinum with excellent results. Initial indications are that the product is of very high stability and has many of the properties of the platinum alloy or intermetallic materials previously studied (RP2100-5). Catalyzed titanium carbide appears to show somewhat higher activity than platinum on a carbon support on a per-unit-area basis and future work will emphasize additional treatments to still higher activity. This material shows great promise as an advanced catalyst that may eventually improve heat rates by 500 Btu/kWh, giving an ultimate end-of-life value of 7800 Btu/kWh (HHV) for a negligible increase in cell component cost.

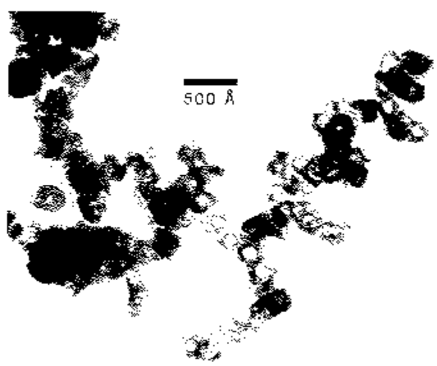


Figure 1 Transmission electron micrograph (340,000×) of very high surface area titanium carbide catalyst support developed under RP1200-8.

Such a catalyst layer may require changes in other cell repeat components. Further, unless electrolyte management can be very carefully controlled (which is improbable), it will be difficult, if not impossible, to make separator plates from graphite-resin mixtures carbonized at low temperatures. Plates made in this way are porous and have a relatively low corrosion resistance, as studies under RP1200-2 have shown. Other work conducted under RP1200-2 has demonstrated much lower corrosion rates on certain fully graphitized materials, and more particularly on dense glassy carbons prepared at 2000°C.

A range of corrosion currents under utility fuel cell cathode conditions is obtained on graphites of different origins and with different preparation conditions. However, operations requiring temperatures of up to 2900°C to produce dense, corrosion-resistant graphite are costly and have high reject rates; thus some low-cost applications of chemically resistant nonporous coatings are being investigated. These will use glassy carbon or chemical vapor-deposited (CVD) carbon coatings (RP1200-2) or conductive CVD carbide coatings (RP1200-8) on bipolar plate components heat-treated at lower temperatures in the 1200–1600°C range.

If any of the above research is successful, it should allow heat rates on the order of 7800 Btu/kWh to be attained in first-generation methane or light distillate systems. If all the research is successful, it could result in values perhaps as low as

7200 Btu/kWh in cells operating at approximately 240°C.

Synthesizing and testing new acid electrolytes

Phosphoric acid does not have all the properties of an ideal fuel cell electrolyte (*EPRI Journal*, September 1982, p. 56). Because it is chemically stable, is relatively involatile at temperatures above 200°C, and rejects carbon dioxide, it is useful in utility fuel cell power plants that use fuel cell waste heat to raise steam for reforming natural gas and liquid fuels. Although phosphoric acid is the only common acid combining the above properties, it does show inferior performance as an air electrode medium compared with other electrolytes, including such materials as sulfuric and perchloric acids, whose other chemical properties render them unsuitable for utility fuel cell use.

Recent work points toward anion adsorption as the major contributor to the relatively poor catalytic performance of phosphoric acid electrolyte, especially in the concentrated form present in the utility fuel cell. For example, RP1676-2 has shown that the high oxygen electrode activity of dilute trifluoromethane sulfonic acid is proportionately reduced by addition of phosphoric acid at increasing concentration. Under these conditions, the poisoning effect on the reaction is so great that changes in the oxygen reduction rate are seen at phosphate ion concentrations as low as 300 ppb. However, while suggesting that adsorption influences the reaction, this experiment showed neither the precise mechanism of the interaction nor the effect of high concentrations of phosphate ion on the process.

Some of the uncertainty has been cleared up by work conducted under RP1200-9, which has recently examined phosphate adsorption in more-concentrated solutions on a platinum oxygen reduction catalyst by a radioactive technique. Phosphate ion adsorbs on the platinum electrode surface at potentials close to those at which high current densities for oxygen reduction are noted, but it is progressively desorbed at higher potentials where the platinum surface becomes more oxidized. In contrast, the anion of trifluoromethane sulfonic acid is hardly adsorbed on the unoxidized platinum surface, but at higher potentials its adsorption is associated with oxidation products of water (or reduction products of molecular oxygen) on the electrode. This observation gives some clues as to the type of interaction required for highly effective catalysis.

Work conducted under RP1200-7 during the last few months has shown that addition of concentrated trifluoromethane sulfonic acid to concentrated phosphoric acid enhances the activity of the latter for oxygen reduction by 40 mV (which could improve the heat of first-generation fuel cells by 400 Btu/kWh). This contrasts with the RP1676-2 results reported above for dilute solutions; however, it shows the real possibility that the catalytic activity of platinum-based catalysts in phosphoric acid can be improved under utility fuel cell conditions by the use of suitable additives, especially fluorinated sulfonic or phosphonic acids.

Efforts to synthesize suitable nonvolatile, stable fluorinated sulfonic or phosphonic acid compounds to replace phosphoric acid (trifluoromethane sulfonic acid is much too volatile for practical use) are continuing (RP1676-1, -3). A year ago there was some doubt whether activity of higher nonvolatile members of the fluorinated sulfonic acid family was equivalent to that of the volatile lowest member of the series, trifluoromethane sulfonic acid. The latest work under RP1676-2 shows that their activities are equal in the absence of impurities resulting from by-products of the synthesis. The result allows some guarded optimism that the present research will ultimately prove to be successful, which has encouraged other organizations (in particular the Gas Research Institute) to support work in this area.

However, not all research problems are resolved at this time. One serious difficulty that was not anticipated when work started in this area is that under utility fuel cell conditions the conductivity of 95% phosphoric acid is more than 10 times higher than that of 89% tetrafluoroethane disulfonic acid (a stable, nonvolatile higher homolog of trifluoromethene sulfonic acid). Unfortunately, the conductivity values of the latter types of acid appear to be the rule, with phosphoric acid the exception.

One consequence of this problem is that fuel cells operating on pure fluorinated sulfonic acids as electrolytes show better intrinsic oxygen electrode activity than those with phosphoric acid, but at the same time they show higher cell resistance, which negates their catalytic advantage. Further understanding of the anomalously high conductivity effect of phosphoric acid is therefore required to see if it can be extended to other materials. The effect appears to be associated with the self-ionization of phosphoric acid, so that the conducting species (protons) are associated with phosphoric acid molecules rather than with water molecules, as in the fluorinated sulfonic acids. Investigation of other additives to unlock these protons and to increase their mobility to levels similar to those in concentrated phosphoric acid is proceeding at the present time.

Molten carbonate and other high-temperature cells

Part of RP1676 is devoted to a study of the high-temperature solid-oxide fuel cell operating on internally reformed natural gas (methane) fuel. This system may be capable of a heat rate of 6800 Btu/kWh (HHV) when combined with a bottoming cycle. This work will allow comparison between this solid-oxide concept and the internal-reforming, methane-fueled molten carbonate system. Because of its higher unit cell voltage, the latter may be capable of lower heat rates than the above value without a bottoming cycle, as indicated in the September 1982 status report. This heat rate has been confirmed in a study carried out as part of RP1041, which concluded that an atmospheric pressure stack of molten carbonate cells with anodes containing an internal-reforming catalyst associated with a very simple chemical-engineering system (three blowers and one simple heat exchanger, compared with turbochargers and 14 heat exchangers for pressurized phosphoric acid) would be capable of very high system efficiency at low cost. Based on present knowledge of laboratory cell performance at 160 mA/cm² current density and at 650°C operating temperature, overall efficiency on natural gas projects to 61% LHV (5600 Btu/kWh, or 6200 Btu/kWh HHV). A total delivered equipment cost of \$600–\$650/kW (1983 \$) in modular units of 2 MW is predicted. Performance improvements using more-complex pressurized systems appear to be small and not cost-effective. This information, confirming previous less-detailed studies for the Gas Research Institute, has caused a reorientation of RP1085 toward the examination of this concept. Consequently, studies are now being directed toward solving remaining problems, particularly the development of long-lifetime internal-reforming catalysts, cathode materials improvements, and the solution of remaining electrolyte management problems. The development of a cost-effective stack is being addressed under RP2344, starting with an in-depth materials and engineering analysis of repeat component design and assembly requirements for a designed-to-cost system. *Project Manager: John Appleby*

MATERIAL-PROCESSING LASERS

Material-processing lasers are a new class of manufacturing tool that is being used increasingly in many industries. In the United

States alone, over 6100 lasers are used to cut, weld, drill, harden, or scribe on a variety of materials ranging from cloth to cobalt alloys. The high-energy densities attained with lasers make possible new applications that outperform many traditional machining operations.

An EPRI project has identified over three-fourths of the lasers used in the U.S. industrial sector (RP1967-3). Some 32 different standard industrial classification (SIC) code industries use lasers. Most of these industries—automobile components and accessories, heavy ordnance, and aircraft engines—are concentrated in the upper Midwest (Michigan, Indiana, Illinois, Iowa, Minnesota, and Wisconsin). The study concluded that utilities in this region will probably have the highest growth rates in electricity demand that result from laser use. Material-processing lasers consumed an estimated 27.5 GWh of electricity (1980). High-powered lasers (5 kW and greater) account for 90% of this electricity consumption.

Lasers produce concentrated electromagnetic energy in a narrow frequency band. Power intensities exceeding millions of watts per square inch are available. The related densities can melt or vaporize materials in nanoseconds. Lasers' versatility is further demonstrated by their ability to diffuse a beam from a tiny spot for welding or cutting to larger areas for heat treating or cladding.

Lasers are most useful when used on extremely hard materials or product designs requiring intricate patterns. A material's hardness does not deter laser operation as it does with conventional tools. Because cutting or drilling is performed by a beam, there is no need to replace or sharpen tools. Thin materials ($\leq 1/8$ in) can be cut or drilled several times faster than by conventional means, and setup work is often eliminated. For example, drilling keyholes in complex patterns for repositioning the cutting tool is no longer necessary.

The laser's ability to cut complex patterns is limited only by the capabilities of the beam delivery system. Computer operation allows almost any pattern to be cut merely by a change in optics and software. Compared with conventional processes, lasers can apply heat locally and rapidly quench it to substantially reduce the total energy absorbed by the material being processed. This feature results in less part distortion and surface damage.

Laser welding is particularly well suited to automation. This process is fast and extremely clean compared with resistive or arc welding. Laser welding precision results in less distortion and surface damage, which eliminates postweld processing.

Special techniques recently developed can perform welds considered difficult or impossible with conventional methods. Welding a thin material to a much thicker substrate with conventional techniques is considered a difficult task. Thinner materials tend to overheat. Spike-through welding with lasers penetrates the top of a thin material and forms a keyhole into the substrate, completing a clean weld.

Heat treating with lasers requires a beam of uniform intensity to heat the surface of steel or iron very quickly to a temperature near its melting point. When the beam is switched off, the heated area rapidly cools and dissipates the heat into the adjoining material. This rapid cooling hardens the material at the surface. The localized beam can selectively harden small areas of the surface while preserving the structural integrity of the treated part. Case depth is readily controlled by adjusting beam intensity. Localized hardening and selective case depth are desired for such applications as hardening gear teeth. A hard surface is necessary to reduce wear, but extensive hardening of the entire gear would make it brittle and unusable.

Laser cladding, a recent application, requires high energy intensities to melt a coating of material with desirable properties onto a less costly substrate. Stellite and cobalt alloys are used on a steel substrate to improve wear resistance, as are nickel-based alloys for high-temperature corrosion resistance. Cladding expensive chromium, cobalt, and nickel onto less-expensive substrates offers an excellent way to reduce the cost of parts requiring these materials.

The ability of material-processing lasers to increase productivity is qualitatively documented. However, not only is quantitative information on productivity enhancement unavailable, but generation of this information is hindered by the absence of relevant application data in the literature.

RP1967-3 surveyed relevant applications and, where available, estimated cost savings in each operation (Table 1). The study also found that laser heat treating applications will abound in the near term. Another project (RP1967-5) is investigating the effectiveness of absorptivity enhancement coatings for materials exhibiting low absorptivity (i.e., copper and its alloys, silver, and others). Procedures for grading enhancement coatings for a variety of substrates are being developed. Coatings being evaluated include graphite, manganese phosphate, potassium disilicate, and black nickel. These coatings will allow lasers to process materials that normally could not be worked.

A new project will compare the qualities of laser-hardened steel with conventional gas-carburizing techniques (RP2416-15). Laser hardening of gears can significantly reduce energy and processing costs in many cases; however, few technical data are available on the properties of laser-hardened steels. This project will compare simulated gear tests of laser-hardened surfaces with established data for gas-carburized surfaces. *Project Manager: John Brushwood*

Table 1
ESTIMATED SAVINGS FROM LASER APPLICATIONS

Application	Cost Savings	
	$/part	$/year
Weld, pulley housing	0.11	405,000
Weld, planetary gear housing	0.08	648,000
Weld, oxygen sensor	0.06	233,000
Weld, emission control valve	0.06	183,000
Harden, power steering cylinder	0.11	499,000
Harden, front wheel bearing	0.15	200,000
Harden, cylinder liner	10.80	324,000
Weld, emergency storage battery	3.13	250,000
Drill, jet engine combustion liner holes	72.69	233,000
Weld, heart assist battery	2.53	308,000

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

IRRADIATED CRACK ARREST

Crack arrest testing is one of the ways in which we can measure the behavior of structural materials that contain cracklike flaws under complex stress fields. Nuclear pressure vessels must be analyzed for both unusual loading and potentially degraded material conditions. Neutron irradiation causes reactor vessel materials to be less tolerant of flaws than they are when constructed. Theories have been developed to forecast the irradiation effect, but theories are always uncertain until they are verified by experiments. RP1326-1 provides the first evidence to measure the effect of neutron irradiation on the arrest of running cracks in reactor pressure vessel steels.

The principles of fracture mechanics are now being used extensively in the nuclear industry. The criterion for failure in the presence of a cracklike defect is that failure will occur whenever the cracktip stresses exceed some critical condition. The loading or stress condition is expressed in terms of the applied stress intensity, K_I. The material strength is expressed in terms of the fracture toughness, and the case of a running crack involves a special material property called the crack arrest toughness, K_{Ia}.

The toughness of ferritic steels is a function of the temperature at which the steel is stressed; the lower the temperature, the lower the toughness. The region of temperature at which a steel changes rather abruptly from low toughness (brittle region) to high toughness (ductile region) is called the transition temperature. The higher this transition temperature for a given material relative to the service loading temperature, the greater is the chance for the material to fail in the presence of a flaw. The Charpy impact energy test and the crack arrest toughness test both shift upward in the transition temperature region as a result of high-energy neutron irradiation. This behavior is a basis for the idea to monitor the temperature shift in toughness of actual vessel materials by measuring the temperature shift of small Charpy specimens in actual power reactors. It is commonly assumed that the shift in the Charpy 30-ft-lb (40.7-J) level (T_{CV30}) will reflect the shift of the toughness behavior.

Any defect discovered during an in-service inspection that exceeds 2.5% of the pressure vessel wall thickness requires an evaluation of its potential effect on the integrity of the vessel. Such an evaluation is outlined in Section XI of the ASME Code to determine the necessity for repairing the defect. Repair is always a costly endeavor. The ultimate acceptability of the defect is related to its size, the severity of loading (under both normal and faulted conditions), and the available fracture toughness of the material. At present, the code requires use of crack initiation and the crack arrest toughness for conservatism in the analysis. If the defect is located in a high fast-neutron flux region of the reactor vessel, then the effect of the irradiation must also be accounted for.

Although measurement and analysis of crack initiation has been pursued extensively, crack arrest is less well understood. However, crack arrest technology has advanced considerably over the past decade. Reproducible test procedures have been developed and are in the process of being standardized. Procedures developed in this project (RP1326-1) are currently under consideration for adoption by ASTM.

Almost all the pressure vessels produced today, and those currently in service, are fabricated from ASTM A533 Grade B, Class 1 or A302 Grade B steel plate or the equivalent forging grade steel, A508 Class 2. The thick sections are, for the most part, joined by submerged arc welding techniques. A number of the early light water reactor vessels were constructed from materials having high copper and nickel content. Copper and nickel have been determined to be two residual elements that contribute to the radiation sensitivity of reactor vessel materials. The materials chemistries in more recently built reactor vessels have controls to reduce the detrimental residual elements and produce vessels more tolerant to the irradiation environment. Consideration of these facts led to the selection of four material types for testing in this project.

Materials selected included two A533 Grade B, Class 1 RPV plates and two submerged arc weldments. One plate and weldment were characteristic of current reactor vessel materials with low RT_{NDT}, high upper-shelf Charpy impact energy, and low copper content. RT_{NDT} is a measure of the transition temperature based on Charpy tests and nil ductility transition tests. The other plate and weldment are characteristic of earlier reactor vessel material with higher RT_{NDT}, lower upper-shelf impact energy, and higher copper content. Table 1 summarizes the four materials tested in the program.

Although the main objective of this project has been to measure the crack arrest toughness, other material property measurements have been included so that the four selected materials would be more fully characterized. In addition to measuring crack arrest toughness values, the program obtained data on tensile properties, Charpy V-notch impact properties, and crack initiation toughness values. When the program is completed, all property measurements will be entered into

Table 1
FOUR MATERIALS TESTED FOR CRACK ARREST TOUGHNESS

Material	Type	Initial RT_{NDT} (°C; °F)		Average Upper-Shelf Impact Energy (ft-lb; J)		Copper Content (wt%)	Phosphorus Content (wt%)
Plate 1	A533 B Class 1	−18	0	124	168	0.07	0.008
Plate 2	A533 B Class 1	−3	27	80	108	0.20	0.010
Weld 1	SA, Linde 0091 flux	−46	−50	158	214	0.03	0.004
Weld 2	SA, Linde 80 flux	−18	0	67	90	0.23	0.012

the EPRI materials data bank, which is maintained for utility and industrial use.

It was evident at the outset of this investigation that the majority of crack arrest specimens to be tested would have to be smaller than the 200 × 200 × 50 mm dimensions recommended by ASTM. The requirement for smaller specimens was dictated both by the limited availability of test material and by space limitations in reactors. To meet these limitations, researchers decided to irradiate brittle-weld compact crack arrest (BWCCA) specimens as small as 100 × 100 × 16 mm. Since BWCCA specimens of this size had not been tested previously, it was necessary to establish the suitability of subsize BWCCA specimens for measuring crack arrest properties of pressure vessel steels.

Loading is applied by forcing a split wedge into a circular opening. A brittle weld helps to initiate a running crack in the specimen, and side grooves control the direction of crack jump. The objective of a crack arrest test is to cause a crack to begin running and stop within the specimen so that an analysis of the specimen test can be used to predict the behavior of hypothetical running cracks in real pressure vessels.

Specimens to be irradiated were carefully packed into specially designed aluminum capsules, which were then placed near the core of the University of Virginia research reactor for exposure to high-energy neutrons. This is a well-characterized swimming pool reactor that uses plate-type fuel elements. It can operate at up to 2 MW of power. Temperature of the test specimens during irradiation was maintained at 288 ± 28°C to match the nominal operating temperature at the inner wall of the reactor vessel. This was accomplished by balancing the heat input from the irradiation and auxiliary electric resistance heaters with the heat lost by conduction through the capsule walls. Dosimeters in each capsule were analyzed after irradiation to measure the neutron fluence. In all cases, the fluence was approximately 1×10^{19} neutrons/cm².

Although the unirradiated specimens in this project were fracture-tested in a temperature-controlled environment only, the irradiated specimens had to be remote-tested and temperature-controlled in radiation hot cells. More than 50 valid crack arrest toughness tests were performed, approximately 30 of them in the irradiated condition.

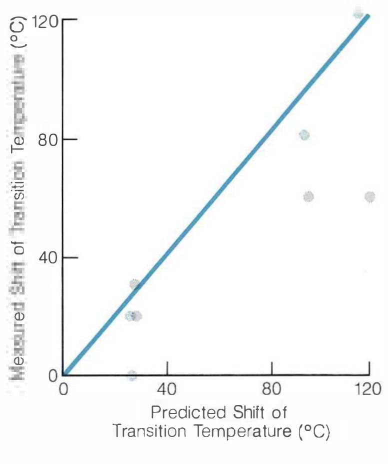


Figure 1 Comparison of observed and predicted effects of radiation on the transition temperature of four steels. The data points in color represent T_{CV30} from the Charpy curve; those in gray represent the K_{Ia}-versus-temperature curve.

The results of the crack arrest tests show that the toughness-versus-temperature relationship is shifted upward in temperature by irradiation, as expected. For the low-copper plate and low-copper weld, the irradiation-induced shift was approximately equal to the shift predicted by NRC Regulatory Guide 1.99 for a neutron fluence of 1×10^{19} neutrons/cm² at 288°C. For the high-copper plate and the high-copper weld, the irradiation-induced temperature shift in the crack arrest toughness curve was less than that predicted by NRC Regulatory Guide 1.99 and less than the observed shift in the Charpy V-notch energy-versus-temperature curves. Figure 1 shows averaged results for the four materials.

The results of this first systematic study of irradiation effects on crack arrest toughness indicate that either NRC Regulatory Guide 1.99 or Charpy V-notch impact test results will provide conservative estimates of the irradiation-induced temperature shift for high-copper plates and welds. *Project Manager: S. W. Tagart, Jr.*

ELECTRICAL EQUIPMENT QUALIFICATION

In close coordination with an advisory group of utility representatives, EPRI has established a wide-ranging research effort to address utility needs in the qualification of safety-related electrical equipment for operation during years of service, as well as under accident conditions that may occur in a plant that is in an advanced stage of life. The research began with an in-depth review of equipment-aging technology and a compilation of information on radiation doses that degrade properties of organic materials in plant equipment. A computerized data bank of equipment qualification information *was then established to make the existing data base available at office terminals of qualification engineers. Also in progress are (1) shake table tests to examine the need to artificially age equipment prior to seismic qualification testing, and (2) hydrogen burn tests to provide generic data that can be used to assess the ability of equipment to function during and after postulated degraded core accidents.*

At a moment's notice, nuclear plant safety equipment may be required to prevent accidents, sense accidents, shut a plant down safely, and monitor postaccident environments. Equipment qualification is the documented demonstration that such equipment, regardless of how long it has been in service, is capable of functioning even under the severe environment it may face during a design-basis accident. Utility owners are responsible for meeting IEEE Standard 323, which requires qualification by test or analysis under such operating environments as cycling, vibration, humidity, and low radiation levels, as well as under such accident environments as earthquakes; water/chemical sprays; and high temperature, pressure, and radiation levels. The most difficult technical problem in qualification stems from the 1974 standard, which requires that equipment be artificially aged before being tested under accident conditions. This accelerated aging attempts to duplicate the equipment's condition after as much as 40 years of installed life.

Qualification technology is relatively immature, and procedures, standards, and regulations in this area have been changing over the last 10 years, making it difficult and costly for utilities to keep abreast. In 1979 the Nuclear Regulatory Commission initiated an extensive evaluation of electrical equipment environmental qualification in operating plants. The result was the establishment of deadlines for eliminating deficiencies and a rule modifying the interim evaluation requirements. Regulatory attention is now shifting to seismic qualification of both electrical and mechanical equipment.

To help utilities keep pace with these expanding regulatory requirements in a manner consistent with the state of the art, EPRI established a wide-ranging research program with the help of an advisory group of utility representatives. The electrical equipment research area was established about five years ago (RP890, RP1707). More recently, the Institute initiated a separate project to study criteria and methods for qualifying active mechanical equipment (RP2198).

An early EPRI study that has been used extensively in the industry is a review of equipment-aging theory and technology by the Franklin Research Center (NP-1558). This report contains a useful summary of aging data, such as aging mechanisms, failure modes, activation energies, and radiation endurance data. It also points out the limitations of existing theories and procedures for quantitatively accelerating the effects of aging.

The Equipment Qualification Advisory Group, made up of representatives from all nuclear plant owners, meets at least twice yearly with EPRI staff and contractors to review current and planned equipment qualification research and to foster information exchange and cooperation among its members. One of the group's more successful cooperative cost-saving efforts was a generic qualification test program on pressure transmitters, the cost of which was shared by about 25 utilities. The advisory group's steering committee helped develop industry position papers on important licensing issues and recently helped create an equipment qualification seminar, sponsored by the Nuclear Safety and Analysis Center (NSAC), which is being presented nationwide during 1983.

Equipment qualification data bank

Until recently each utility collected its own qualification data for plant-specific electrical safety equipment, which resulted in expensive duplication. The sheer quantity of information about hundreds of equipment types in each plant made it difficult to determine work already performed elsewhere, and this situation was aggravated by the exercise of proprietary rights by utilities, vendors, and test laboratories. EPRI responded by establishing the Equipment Qualification Data Bank (EQDB), which contains information on the qualification of all electrical safety equipment in nuclear plants.

Operational since January 1981, EQDB is an interactive, time-shared computer system containing summary qualification data for about 7000 electrical equipment items in 88 operating and not-yet-operating plants. The data are extracted from documents submitted to NRC or are contributed directly by plant owners and equipment manufacturers. However, the appearance of data in EQDB does not imply that the qualification of a particular device is accepted by NRC.

Each device's summary consists of over 40 items of information, including equipment identifiers, peak environmental parameters, qualification test parameters, and information sources. From terminals in their offices, industry users can search the data files by equipment type, manufacturer, plant, test temperature, pressure, humidity, or radiation dose. The data bank can also serve as a catalog for plant operators who need replacement equipment on short notice. EPRI is supporting EQDB's expansion to include seismic qualification data for both electrical and mechanical equipment and is planning to add material property data on aging and radiation effects.

EQDB, which was established with EPRI research funds (RP1707-2), is now maintained and operated by annual user fees to NUS Corp., which administers the data bank for EPRI. There are currently about 20 subscribers (mostly utilities).

Radiation effects studies

EPRI is also compiling radiation effects information on organic materials in nuclear plant equipment for eventual storage in the data bank. The data can be used directly to qualify equipment for radiation in mild-environment plant areas, for which lifetime radiation doses are generally 10^4 rads or less. The data are also useful in selecting materials and components to function in harsh environments—those having lifetime-plus-accident doses estimated to be as high as 10^9 rads.

The objective of an EPRI-sponsored study by Georgia Institute of Technology (RP1707-3) was to determine, to the extent possible, a low-level radiation threshold dose for significant effects to nuclear plant materials and components, using data in published literature. The research studied 50 plastics, 16 elastomers, coatings, lubricants, and adhesives. An important finding is that a total dose of less than 10^5 rads produces no significant degradation of mechanical or electrical properties for the listed materials (NP-2129). (The notable exception is equipment containing Teflon, for which the threshold dose is 10^4 rads.) Some organic materials were found to exhibit threshold levels as great as 10^9 rads. The study showed that, in general, equipment exposed to less than 10^5 rads during its design life can be exempted from radiation testing. A follow-on study of radiation effects is being carried out by the Jet Propulsion Laboratory, California Institute of Technology (RP1707-7). The objectives are to compile existing radiation effects data for organic materials into a format suitable for EQDB and to transfer applicable radiation effects technology from the space program to the nuclear power industry.

Materials experts from a cross section of the industry are forming an EPRI-supported qualification materials data committee, which will review radiation effects and other aging data for storage in the data bank to ensure that properties used to qualify plant equipment are uniform.

Aging-seismic correlation tests

Qualification standards specify that electrical equipment be aged before seismic testing. Although this requirement addresses the possibility that degradation such as embrittlement or corrosion could impair the ability of an electrical device to function during or after an earthquake, there is little documented evidence from laboratory testing or operating experience to show a correlation between aging and functionability under seismic excitation. To examine this aging-seismic correlation, EPRI is sponsoring tests at Wyle Laboratories (RP1707-4). The project's first phase addressed electronic and electrical devices (e.g., capacitors, diodes, transistors, integrated circuits, an optical coupler, and terminal blocks) for which seismic qualification testing had shown no aging-seismic correlation.

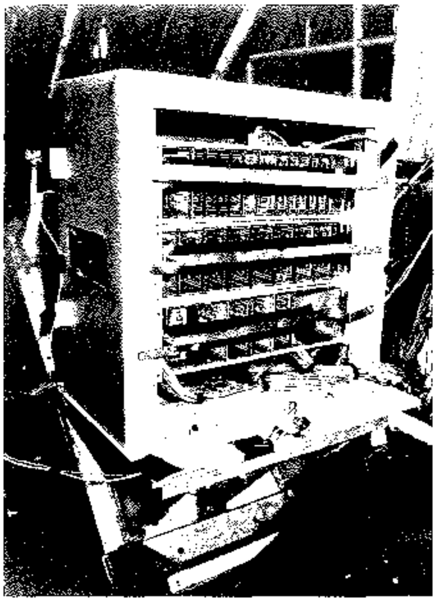
Researchers constructed a statistical experiment in which several model specimens from each component category were seismically tested. Some were new; some were aged thermally; others were aged operationally by cycling; and still others were aged both thermally and operationally. Equivalent-aged life ranged from 7 to 225 years. The research hypothesis was that component seismic performance would not be affected by aging. As a control, two relay types, the seismic performance of which was suspected to be affected by aging, were included.

The components, numbering about 2000, were installed in a metal cabinet in a manner typical of nuclear plant installation. The cabinet was mounted on a biaxial shake table (Figure 2), and motion—the same used in many other qualification tests at Wyle Laboratories—was applied successively in two orthogonal directions.

None of the components suspected to be unaffected by aging malfunctioned either during or after any of the tests. The result was a recommendation that similar nuclear plant components be exempted from pretest aging in the future. By eliminating such equipment conditioning, utilities could benefit from substantial savings without jeopardizing demonstrated safety.

One of the five relays that had been both thermally and cyclically aged exhibited contact chatter at several seismic test levels.

Figure 2 Electric cabinet mounted on biaxial shake table for the aging-seismic correlation tests of 2000 aged and unaged components.



Researchers concluded that relays may be affected by aging. However, additional testing with a greater sample size is necessary before a statistically sound conclusion can be drawn.

The study's second phase, now in progress, is testing additional relays and component types with and without anticipated correlation. Some of the components are larger and more complex (e.g., switches, motors, solenoids, meters) than those tested in the first phase. The second phase also includes devices that have been naturally aged in operating plants. Results are expected by mid 1984.

Hydrogen burn tests

The Three Mile Island accident provided a real-world test of nuclear plant systems and equipment. In almost all respects the accident environment was less severe than the design-basis environment for which the equipment was qualified. However, during the accident an abnormal 28-psi (193-kPa) pressure spike was measured in the containment building. This pressure has been attributed to the burning of hydrogen released to the containment atmosphere from the metal-water reaction inside the reactor vessel. Although the pressure is covered by current environmental qualification conditions, the associated temperature spike is not.

Proposed regulations will require that equipment be able to function during and after a hydrogen burn. The key question is whether the conservative methods currently used to qualify equipment can ensure the equipment's ability to survive a hydrogen burn. EPRI began to examine this issue by conducting hydrogen burn tests in a 2-m-diam cylindrical steel vessel (RP1932). Six tests were conducted, including ignition of both still (premixed) hydrogen in concentrations up to 10.7% by volume and continuously flowing hydrogen, with and without steam. The equipment—valve operators, pressure transmitters, solenoid valves, limit switches, thermocouples, resistance temperature detectors, and various sizes of cable—is typical of safety equipment in nuclear plants that may be exposed to burns. None of the equipment showed visible signs of degradation after cumulative exposure in all six tests. All functioned normally before, during, and after each test.

The small volume of the vessel for the initial tests was representative of subcompartments in a containment building. To examine phenomena in a space more representative of an open containment volume, follow-on hydrogen burn tests are being conducted in a 15.7-m-diam spherical dewar in a DOE Nevada facility. The tests (RP2168-3), which are a part of EPRI's TMI-2 research, include a wide range of equipment that must function under postulated degraded core conditions. Results should be available early in 1984.

Other areas of research

EPRI is also conducting three other electrical safety equipment qualification projects. The first is a review of surveillance techniques that might be used to monitor equipment condition in situ as it ages during plant operation (RP1707-9). These special techniques measure equipment parameters, the change of which over time may be a useful indication of remaining life. The second is a series of generic qualification studies for equipment commonly installed in plant areas with mild environments. Studies on rotary hand switches (RP1707-8) and motors (RP1707-10) are compiling existing test data and analyses that can be used to support qualification of these devices without additional plant-specific testing. The third study (RP1707-11) is attempting to use military test data to show that some equipment types are inherently failure-proof under high-frequency vibration such as that produced by activation of safety relief valves in BWR pressure suppression systems. *Project Manager: George E. Sliter*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP639-2	Feasibility Study: MHD Component Product	3 months	64.3	Technology Assessment Group, Inc. *L. Angello*
RP1996-9	Wind Turbine Test Support—Electrical	9 months	32.0	Power Technologies, Inc. *F. Goodman*
RP1996-10	Wind Turbine Test Support—Analytic	1 year	39.3	Nielsen Engineering and Research, Inc. *F. Goodman*
RP2112-2	Evaluation of Coal-Derived Liquids as Utility Boiler Fuels: Eastern Test	11 months	719.2	Southern Company Services, Inc. *H. Schreiber*
RP2421-2	Gas Turbine Life Management System	44 months	2199.8	General Electric Co. *C. Dohner*
Coal Combustion Systems				
RP1184-5	Workshop: Fossil Fuel Plant Cycling	1 year	44.9	Wood-Leaver and Associates, Inc. *F. Wong*
RP1261-7	Treatment of Recirculated Cooling Water; Phase 2, Site 2	2 years	574.8	Stearns-Roger Engineering Corp. *W. Chow*
RP1261-8	Technical Studies and Analysis: Treatment of Recirculated Cooling Water; Phase 2, Site 2	8 months	183.0	Stearns-Roger Engineering Corp. *W. Chow*
RP1648-6	Reliability Improvements: Turbine Generator Lubrication Supply System	2 years	999.9	General Electric Co. *T. McCloskey*
RP2154-3	Retrofit Low-NO_x Combustion Systems for Coal-Fired Boilers	16 months	1247.3	Babcock & Wilcox Co. *M. McElroy*
RP2243-1	Guidelines: Electrostatic Precipitator	21 months	348.3	Ebasco Services, Inc. *R. Altman*
RP2303-2	Environmental Assessment of AFBC Project	16 months	55.9	GAI Consultants, Inc. *C. Aulisio*
RP2385-1	Cooling Pond Performance	30 months	435.9	Massachusetts Institute of Technolgy *J. Bartz*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Electrical Systems				
RP1534-2	Operating Considerations: Reliability Modeling of Interconnected Systems	22 months	348.1	Associated Power Analysts, Inc. *N. Balu*
RP2115-7	Feasibility Study: Liquid-Nitrogen-Cooled Ultrahigh Voltage Thyristors	7 months	37.4	General Electric Co. *H. Mehta*
RP2200-1	Using Modeling Techniques to Develop Methods for Predicting URD Cable Corrosion	20 months	299.9	Harco Corp. *T. Kendrew*
RP2325-1	Improved Radio Frequency Monitoring	14 months	348.8	Westinghouse Electric Corp. *J. Edmonds*
RP2431-1	Lightning Flash Density Measurement	17 months	677.9	State University of New York *H. Songster*
RP2438-1	Long-Life Cable Development: Cable Processing Survey	11 months	135.0	Battelle, Columbus Laboratories *B. Bernstein*
RP2445-1	Low-Cost Gas Monitor for Oil-Filled Transformers	30 months	193.8	Westinghouse Electric Corp. *V. Tahiliani*
Energy Analysis and Environment				
RP1955-4	Annual Review of Demand and Conservation Research	8 months	74.3	Battelle Memorial Institute *A. Faruqui*
RP2020-3	Measurements of Bioavailability of Hg Species in Fresh Water and Sediments	23 months	129.4	Battelle, Pacific Northwest Laboratories *J. Huckabee*
RP2145-3	Residential End-Use Load Shapes	10 months	99.4	Cambridge Systematics, Inc. *S. Braithwait*
RP2174-10	Paleoecological Reconstruction of Recent Lake Acidification; Phase 1	9 months	319.6	Indiana University Foundation *R. Goldstein*
RP2279-3	Symposium: Load Research and Load Forecasting	11 months	75.0	Battelle Memorial Institute *E. Beardsworth*
RP2280-1	Groundwater Transport	10 months	319.3	Tennessee Valley Authority *I. Murarka*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2359-3	Fuel Research Coordination and Planning	10 months	51.1	Strategic Decisions Group *H. Mueller*
RP2359-10	Fuel Planning and Management: Application of Decision Analysis Fuel Planning	9 months	160.8	Strategic Decisions Group *S. Chapel*
RP2359-20	Oil and Gas Contract Mix: Application of Contract Mix Decision Analysis Methodology	8 months	84.5	Decision Focus, Inc. *H. Mueller*
RP2365-1	Aluminum Biogeochemistry of Forested Watersheds	46 months	2614.5	University of Maine at Orono *R. Goldstein*
RP2368-1	Laboratory and Field Toxicity Comparisons	20 months	52.2	Cornell University *J. Huckabee*
RP2375-1	Hydrogen Peroxide Spectrometer	1 year	72.2	Unisearch Associates, Inc. *P. Mueller*
RP2379-2	Research Issues in Utility and Industrial Fuel Market Changes	4 months	19.5	Hagler Baily & Co. *H. Mueller*
RP2379-3	Energy Analysis Department; Research Transfer	4 months	30.0	National Economic Research Associates *H. Mueller*
RP2379-6	Simulation of Utility Cash Flows	8 months	29.6	Pugh Roberts Associates *D. Geraghty*
RP2380-4	Alternative Species for Biological Testing	9 months	59.2	Battelle, Columbus Laboratories *R. Brocksen*
RP2380-6	Feasibility Study: Assessing the Use of Data From Remote Sensors	5 months	41.1	The Destek Group *R. Brocksen*
RP2381-4	Demand-Side Management	5 months	192.3	Battelle, Columbus Laboratories *A. Faruqui*
RP2441-2	Model: Strategic Interconnection	6 months	49.7	Lotus Consulting Group *S. Mukherjee*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1275-17	Model: Validation of Energy Management and Utilization	5 months	58.9	Synergic Resources Corp. *S. Hu*
RP1569-7	Evaluation of EV Fleet Applications and Analysis	9 months	40.0	Donald C. Graves, Inc. *J. Mader*
RP1677-8	Integrated Commercialization Analysis for Dispersed Fuel Cell Power Plants	11 months	98.0	Polydyne, Inc. *D. Rigney*
RP1940-6	Load Management Technology Overview	10 months	190.6	Analysis & Control of Energy Systems *V. Rabl*
RP2033-17	Heat Pump R&D Review	11 months	92.2	Strategies Unlimited, Inc. *J. Calm*
RP2216-1	Testing and Development: Electric Vehicle Battery	2 years	655.7	California Institute of Technology *B. Askew*
RP2216-2	Testing and Development: Electric Vehicle Battery	14 months	406.3	Argonne National Laboratory *B. Askew*
RP2285-4	Performance of Electronic Ballasts and Other New Lighting	9 months	82.0	Department of Energy *A. Lannus*
RP2416-8	Separations Research Program Development	1 year	83.4	University of Texas at Austin *J. Brushwood*
RP2416-9	Assessment of Japanese Technology: Electrification Technologies	8 months	27.0	Advanced Materials Technology *L. Harry*
RP2416-11	Microwave Drying Application	7 months	65.2	Thermo Energy Corp. *J. Brushwood*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP694-9	Applications of MMS to Babcock & Wilcox Plant Design	8 months	41.5	Bechtel Group, Inc. *J. Sursock*
RP699-2	Hideout Return Testing	7 months	97.8	Westinghouse Electric Corp. *C. Shoemaker*
RP1398-13	Prototype System for Ultrasonic Inspection of Turbine Disk Rings	9 months	173.0	Southwest Research Institute *M. Kolar*
RP1442-7	Implementation and Support: Advanced Core-Monitoring Framework	17 months	101.8	Nuclear Software Services, Inc. *A. Long*
RP1585-4	Exploration of Advanced LWR Concepts	8 months	60.0	Touro College *A. Adamantiades*
RP1627-5	Assessment and Application of Transient Fuel Behavior Computer Code	8 months	35.1	Texas A&M University System *A. Adamantiades*
RP1702-5	Measurement of Fission Gas Release at H. B. Robinson Unit 2	8 months	187.7	Exxon Nuclear Co., Inc. *S. Gehl*
RP1707-11	Operability of Equipment Under High-Frequency Excitation	1 year	65.2	Los Alamos Technical Associates, Inc. *G. Sliter*
RP1708-2	Evaluation of Thermally Treated Inconel 600 in Faulted Secondary and Primary Water Environments	15 months	265.1	Westinghouse Electric Corp. *C. Shoemaker*
RP1757-22	Topographic Analysis of Fracture Surface	10 months	89.0	SRI International *T. Marston*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1757-25	Development and Verification of Fracture Model	11 months	38.8	Failure Analysis Associates *T. Marston*
RP1842-7	Use of RETRAN for Determination of Some PWR System Success Criteria	9 months	99.9	Energy Incorporated *B. Chu*
RP1843-2	Turbine Generator Fire Protection by Sprinkler Systems	13 months	183.5	Black & Veatch Consulting Engineers *J. Matte*
RP1930-7	Alternative BWR Water Chemistry Monitoring	56 months	1050.6	General Electric Co. *M. Naughton*
RP1931-3	Analysis of ANL Water-Corium Interaction Experiments	7 months	33.2	University of Wisconsin at Madison *D. Squarer*
RP2012-8	Method Development: Postaccident Chemical Decontamination	7 months	211.5	Pacific Nuclear Systems & Services, Inc. *M. Naughton*
RP2012-9	Disposal of Radioactive Decontamination Solution Wastes	7 months	49.7	EDS Nuclear, Inc. *M. Naughton*
RP2079-9	Properties of Recrystallized Alloy 800H and Associated HTGR Steam Generator Design Implications	23 months	233.1	Public Service Co. of Colorado *R. Nickell*
RP2122-9	Downcomer Mixing Heat Transfer for Pressurized Thermal Shock Analysis	1 year	90.0	University of California at Los Angeles *B. Sun*
RP2135-4	Marviken Aerosol Transport Tests	37 months	874.3	Studsvik Energiteknik Ab *F. Rahn*
RP2166-4	Human Engineering Design Guidelines for Maintainability	28 months	633.1	General Physics Corp. *H. Parris*
RP2169-4	Dependent Failure Data Analysis	7 months	138.4	Pickard, Lowe and Garrick, Inc. *D. Worledge*
RP2183-3	Planning Study: Fluid-Thermal Insulation Interactions	3 months	38.3	Westinghouse Electric Corp. *J. Matte*
RP2287-1	Financial Risk from the Operation of an LWR Power Plant	6 months	94.4	General Electric Co. *D. Worledge*
RP2295-3	BWR Cobalt Deposition	23 months	477.3	General Electric Co. *C. Wood*
RP2296-3	BWR Primary System Decontamination	1 year	175.0	Vermont Yankee Nuclear Power Corp. *C. Wood*
RP2296-4	Evaluation of Decontamination Reagent Corrosion	6 months	36.9	Battelle, Pacific Northwest Laboratories *C. Wood*
RP2304-1	Experimental Simulation of Small-Scale B&W Reactor Model	31 months	699.9	SRI International *J. Sursock*
RP2347-8	Universal Fiber Optic Link	6 months	47.1	Babcock & Wilcox Co. *R. Kubik*
RP2348-1	System Interaction Identification and Development of Procedure	10 months	59.4	Energy Incorporated *B. Chu*
RP2348-2	Identification of System Interaction for Probabilistic Risk Assessment Applications	5 months	60.6	Pickard, Lowe and Garrick, Inc. *B. Chu*
RP2351-1	In-Reactor Source Term Experiments	11 months	1408.5	Argonne National Laboratory *R. Oehlberg*
RP2354-10	Oconee Probabilistic Risk Assessment; Supplemental Engineering Study	9 months	42.4	Technology for Energy Corp. *W. Sugnet*
RP2405-2	Backlay Clad Inspection	8 months	33.2	Amdata Systems, Inc. *M. Lapides*
RP2408-1	Field Data Requirements to Predict SCC; Pilot Study	1 year	64.6	Failure Analysis Associates *F. Gelhaus*
RP2410-1	BWR Control Rod Drive Replacement	11 months	71.3	Dominion Engineering *T. Law*
RP2412-1	Monitoring of Chemical Contaminants in BWRs	14 months	181.1	General Electric Co. *M. Naughton*
RP2420-7	Benchmark of RELAP 4/MOD7 Against Semiscale Test S-28	5 months	55.2	Intermountain Technologies, Inc. *J. Lang*
RP2430-7	Institutional/Financial Planning for the Design, Construction, and Operation of a Near-Commercial-Scale LMFBR Plant	3 months	30.0	Reid & Priest *D. Gibbs*
RP2453-1	Steam Generator Tube Rupture; Thermal Hydraulic Simulation Tests	6 months	136.5	Acurex Corp. *S. Kalra*
R&D Staff				
RP2258-1	Effects of Dynamic Strain on Crack Tip Chemistry	22 months	80.1	The University of Newcastle-Upon-Tyne *B. Syrett*
RP2258-2	Model: Effects of Dynamic Strain on Crack Tip Chemistry	19 months	47.9	Battelle Memorial Institute *B. Syrett*
RP2426-1	Model: Expression Characteristics of Utility Steels	1 year	48.0	Westinghouse Electric Corp. *R. Jaffee*

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

Evaluation of Synthetic Fuel Character Effects on Rich-Lean Stationary Gas Turbine Combustion Systems

AP-2822 Final Report (RP1898-1), Vol. 2; $13.00

This volume describes full-scale testing to determine the effects of synthetic fuel characteristics on rich-lean stationary gas turbine combustion systems. Evaluations conducted with a 10-in-diam burner are discussed, and the results are compared with those from tests that used a similar but smaller burner. The contractor is United Technologies Corp. *EPRI Project Manager: L. C. Angello*

Performance of Coal Gasification–Reheat Combustion Turbine Power Cycles Using Dry Cooling

AP-2839 Final Report (RP2029-3); $14.50

A study was conducted to explore the near-term performance potential of coal gasification–combined-cycle systems with reheat combustion turbines and dry cooling. Cycles using the Texaco and British Gas Corp.–Lurgi gasifiers were analyzed. The conditions and assumptions of the study are described, and the results are summarized. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: B. M. Louks*

Point-Contact Silicon Solar Cells

AP-2859 Interim Report (RP790-2); $13.00

A new type of silicon photovoltaic cell called the point-contact cell is under development. This report describes the cell and an analytic model developed for use in design optimization. Necessary future cell development work is discussed. The contractor is Stanford University. *EPRI Project Manager: R. W. Taylor*

Systems Analysis and Ranking of MHD Power Consolidation Circuits

AP-2942 Final Report (RP642-4); $25.00

This report evaluates a number of proposed current consolidation systems for magnetohydrodynamic (MHD) power generators. For each system circuit action is described, performance analysis equations are developed, and digital computer solutions are documented. A performance specification for a large-scale consolidation system is proposed, and an equivalent circuit is described that represents a limited portion of an MHD channel for either digital or analog studies. The contractor is General Electric Co. *EPRI Project Manager: R. J. Ferraro*

Occurrence and Role of Organometallics in Coal Liquefaction

AP-2980 Interim Report (RP1696-2); $20.50

Nine solvent-refined coal (SRC) samples were produced under varied operating conditions and examined for trace metal content and species. Liquefaction reactions were performed to determine the impact of coal, reaction time, atmosphere, temperature, coal pretreatment, SRC post-treatment, and process solvent on conversion and trace metals. This report presents the results and discusses the nature of trace metals and their role in coal liquefaction. The contractor is Virginia Polytechnic Institute and State University. *EPRI Project Manager: L. F. Atherton*

Workshop on Environmental Control Technology for Coal Gasification

AP-3006 Proceedings (WS81-241-01); $46.00

This report contains the proceedings of an EPRI workshop on coal gasification environmental control technology held in July 1982 in Palo Alto, California. The papers presented cover a broad range of topics and represent the work of interested groups in the United States, India, South Africa, and the Federal Republic of Germany. A summary discussion by the workshop planning committee is included. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: W. S. Reveal*

COAL COMBUSTION SYSTEMS

Proceedings: Electrostatic Precipitator Technology for Coal-Fired Power Plants

CS-2908 Proceedings (RP533-5); $43.00

This report presents 39 papers given at an EPRI conference on electrostatic precipitator (ESP) technology for coal-fired power plants. The conference was held in July 1982 in Nashville, Tennessee. Information on ESP fundamentals, the upgrading of conventional ESPs, two-stage electrostatic collection systems, sizing and troubleshooting, and operation and maintenance is included. The contractor is Southern Research Institute. *EPRI Project Manager: R. F. Altman*

6-by-6-ft AFBC Development Facility and Commercial Utility AFBC Design Assessment

CS-2930 Interim Report (RP718-2); $28.00

Data generated from the 6-by-6-ft atmospheric fluidized-bed combustion (AFBC) development facility are presented. This report summarizes the first two years of testing, during which the facility was used to develop a performance data base with respect to these process parameters: coal type and feed size, limestone feed size, bed temperature and depth, coal feed point spacing, fly ash recycle, and excess air. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. J. Aulisio*

Modular Modeling System Validation: Transients in Fossil and Nuclear Power Plants

CS/NP-2945 Interim Report (RP1184-2, RP1163-1); $23.50

This report presents the results of work to validate the modular modeling system (MMS), a computer code package developed to simulate the dynamic performance of power plants, plant subsystems, and components. The accuracy, ease of use, and required computer resources of MMS are evaluated, and the use of MMS to simulate test transients at fossil fuel and nuclear power plants is described. The results are compared with plant test data. The contractor is Bechtel Group, Inc. *EPRI Project Managers: A. F. Armor, S. M. Divakaruni, S. P. Kalra, and A. B. Long*

Limestone FGD Systems Data Book

CS-2949 Final Report (RP1857-1); $50.50

This guidelines manual highlights the design and operating parameters of limestone-based SO_2 scrubbing systems. Information is provided on the design, specification, installation, and operation of a limestone flue gas desulfurization (FGD) system. The important process differences between lime and limestone FGD systems are also discussed. The contractors are Black & Veatch Consulting Engineers and Radian Corp. *EPRI Project Manager: C. E. Dene*

Current Cathodic Protection Practice in Steam Surface Condensers

CS-2961 Topical Report (RP1689-3); $11.50

A survey was conducted to determine current practice regarding the implementation of cathodic protection in the water boxes of steam surface condensers. The important components of a condenser cathodic protection system are discussed, as well as the principal design factors governing component selection. The report also summarizes periodic surveillance procedures, typical maintenance problems, and the use of protective coatings in conjunction with cathodic protection. The contractor is Ocean City Research Corp. *EPRI Project Manager: B. C. Syrett*

Metallurgical Investigation of a Cracked Low-Pressure Steam Turbine Shaft

CS-2984 Final Report (RP700-4); $10.00

This report documents the metallurgical failure analysis of a low-pressure steam turbine shaft that cracked at two locations in approximately 15 years of utility service. The investigation included examinations of the shaft surface, fractographic studies, metallographic examination, tensile tests, and chemical analysis. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: Ramaswamy Viswanathan*

Modular Modeling System: Overview and General Theory
CS/NP-2989 Final Report (RP1184-2, RP1163-1); $17.50

This report discusses the theoretical basis of the modular modeling system (MMS), a computer code for simulating the dynamic performance of fossil fuel and nuclear power plants. Each code module is described, and code validation and testing are reviewed. The contractors are Babcock & Wilcox Co. and Bechtel Group, Inc. *EPRI Project Managers: A. F. Armor, F. K. L. Wong, S. M. Divakaruni, and J. P. Sursock*

ELECTRICAL SYSTEMS

Diagnostic Program Document: Program Extensions
EL-1104 Final Report (RP670-2), Vol. 4; $19.00

This volume describes the fine-tuning of algorithms used by transient stability computer programs. In addition, the implementation of a partitioned approach is discussed, and test results are given. The contractor is Boeing Computer Services, Inc. *EPRI Project Manager: J. W. Lamont*

Electric Generation Expansion Analysis System
EL-2561 Final Report (RP1529-1); Vol. 3, $34.00; Vol. 4, $35.50; Vol. 5, $29.50

Volume 3 of this six-volume report presents the user's manual for the electric generation expansion analysis system (EGEAS), a modular, state-of-the-art capacity expansion software package. Volume 4 is the programmer's manual and Volume 5 the validation manual. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: N. J. Balu*

Measurement and Characterization of Substation Electromagnetic Transients
EL-2982 Final Report (RP1359-2); $31.00

A new approach was developed for measuring and characterizing electromagnetic interference caused by substation transients. A data acquisition system was designed and constructed for field use. Measurements were taken from staged operations in high-voltage substation environments, and the resulting data were analyzed by specialized computer programs developed for this project. The contractor is Texas A&M University. *EPRI Project Manager: S. L. Nilsson*

Railroad Electrification on Utility Systems
EL-3001 Final Report (TPS81-796); $16.00

This report documents a study of the impact of railroad electrification on utility systems. The effort entailed a literature review, discussions with railroads and electric utilities having electrification experience, a review of available computation tools, and quantitative illustrations of the impact of railroad loads on utility systems. The contractor is Power Technologies, Inc. *EPRI Project Manager: N. J. Balu*

Methodology for Integration of HVDC Links in Large AC Systems, Phase 1: Reference Manual
EL-3004 Final Report (RP1964-1); $28.00

This reference manual presents a comprehensive methodology for evaluating HVDC alternatives in utility transmission planning. It provides background information on existing HVDC systems, describes the types of studies and the system modeling required, and discusses potential problems. The importance of proper control of the dc system is emphasized, and examples of previously used control systems are described. The contractor is Ebasco Services, Inc. *EPRI Project Manager: N. J. Balu*

Examination of Distribution Cables for Chemical and Physical Changes Upon Aging in the Field and Laboratory
EL-3011 Final Report (RP1357-3); $10.00

Several traditional polymer characterization tools were used to compare distribution cables aged under accelerated conditions with similar cables recovered from the field and with one cable manufactured many years ago but never energized. In addition, methods were investigated that might be useful in evaluating cross-linked-polyethylene cable insulation. The contractor is the University of Connecticut. *EPRI Project Manager: B. S. Bernstein*

Design Optimization of Metallic Shield–Concentric Conductors of Extruded Dielectric Cables Under Fault Conditions
EL-3014 Final Report (RP1286-2); $16.00

Laboratory tests were conducted to determine maximum metallic shield withstand temperatures under short-circuit conditions for cross-linked-polyethylene-insulated cables with round wire and flat strap shields. A mathematical model and computer program were developed for predicting shield temperature for a given fault current and interruption-reclose sequence. The results of tests on 27 cable constructions are presented. The contractors are Pirelli Cable Corp. and Georgia Power Co. *EPRI Project Manager: H. J. Songster*

Distribution Fault Current Analysis
EL-3085 Final Report (RP1209-1); $26.50

This report documents work to provide an accurate description of the magnitude and characteristics of fault currents experienced on electric utility distribution systems. It describes extensive system measurements and analyses for 50 distribution feeders belonging to 13 utility systems. Actual and calculated fault current magnitudes are compared. The contractor is Power Technologies, Inc. *EPRI Project Manager: H. J. Songster*

PWR Modeling for Long-Term Power System Dynamics Simulations
EL-3087 Final Report (RP764-4); Vol. 1, $14.50; Vol. 2, $23.50

This report discusses the development of a PWR model for incorporation into a computer code for analyzing long-term system dynamics. Volume 1 is an executive summary. Volume 2 presents details of the high- and low-order dynamic models. The contractor is the University of Tennessee. *EPRI Project Manager: J. W. Lamont*

ENERGY ANALYSIS AND ENVIRONMENT

Plume Conversion Rates in the SURE Region
EA-1498 Final Report (RP860-1), Vol. 3; $13.00

This volume describes modeling studies of chemical transformations in plumes from fossil fuel power plants during the first several hours of plume transport. The work involved the development and application of a two-dimensional photochemical plume model, as well as further analysis of aerosol data from an earlier EPRI plume study. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: Charles Hakkarinen*

Time Variability of Elemental Concentrations in Power Plant Ash
EA-2959 Final Report (RP1620); $17.50

In a pilot study at a southwestern power plant, coal and coal ashes were analyzed chemically for 14 inorganic elements, and the data were statistically analyzed to estimate the time variability of the chemical composition of coal ashes. The results show that time, sampling, sample preparation, and sample analysis contribute to the total variability of ash composition. The contractors are Stanford University and Radian Corp. *EPRI Project Manager: I. P. Murarka*

Proceedings: Fuel Supply Seminars
EA-2994 Proceedings (RP1981-11); $31.00

This report contains papers given at the EPRI fuel supply seminars held in St. Louis in October 1982. The papers present an up-to-date assessment of critical issues affecting fuel supply and utility fuel planning. The chief topics are coal, oil and gas, uranium, and coal conversion. Ongoing EPRI research is summarized, and recent oil and gas supply and demand forecasts are reviewed. The contractor is Atlantis, Inc. *EPRI Project Manager: Jeremy Platt*

Selected Papers on Fuel Forecasting and Analysis
EA-3015 Proceedings (RP1981-1, -2, -3); $23.50

This report presents selected papers from an EPRI seminar on fuel forecasting and analysis held in December 1981 in Memphis, Tennessee. The papers cover coal, uranium, oil, and gas issues and related EPRI research projects. Two additional papers prepared for this volume address the use of coal supply forecasting models and the relationship between coal and oil prices. The contractors are Pennsylvania State University and Atlantis, Inc. *EPRI Project Manager: Jeremy Platt*

ENERGY MANAGEMENT AND UTILIZATION

Roughness Evolution and Dendritic Growth in Zinc Electrodeposition From Halide Electrolytes
EM-2937 Final Report (RP1198-3); $16.00

This report describes a comprehensive model for roughness evolution in electrodeposition. The model takes into account the effects of transport by diffusion and convection, reaction kinetics, and surface energy. Critical overpotentials for roughness initiation and propagation are determined.

The contractor is Case Western Reserve University. *EPRI Project Manager: D. L. Douglas*

Issues in Residential Load Management
EM-2991 Final Report (RP2035-1); $10.00

This report discusses the current status of residential load control equipment and program implementation. Emphasis is on local control systems—nonstorage options that give the customer partial control over the managed electric load. The project involved interviews with equipment suppliers and developers and a workshop where equipment suppliers, utility representatives, and researchers could exchange information and identify unresolved issues in residential load management. The contractor is Strategies Unlimited. *EPRI Project Manager: V. A. Rabl*

Evaluation of Thermal Energy Storage Materials for Advanced CAES Systems
EM-2999 Final Report (RP1699-2); $13.00

Four thermal storage media—iron oxide pellets, Denstone pebbles, cast-iron balls, and Dresser basalt rock—were evaluated to determine the most desirable material for use in adiabatic and hybrid advanced compressed-air energy storage (CAES) systems. Bench-scale laboratory tests were conducted to investigate the materials' thermal cycling durability, particulate formation, and corrosion resistance. The contractors are Battelle, Pacific Northwest Laboratories and Fluidyne Engineering Corp. *EPRI Project Manager: R. B. Schainker*

Utility Impacts Assessment of Residential Passive Solar Systems
EM-3092-SY Summary Report (RP1666-1); $8.50

This report summarizes work to provide the electric utility industry with a tool for analyzing the advantages and disadvantages of passive solar residential construction within a service area. The resulting methodology is discussed, as well as the results of tests conducted with seven cooperating utilities. The contractor is JBF Scientific Corp. *EPRI Project Manager: G. G. Purcell*

NUCLEAR POWER

VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores
NP-2511-CCM Computer Code Manual (RP1584-1); Vol. 1, $22.00; Vol. 2, $46.00

Volume 1 details the mathematical modeling of the VIPRE code, which was developed for nuclear power utility thermal-hydraulic analysis applications. It describes the theoretical development of the general equations, constitutive relationships, correlations, and numerical solution techniques. Volume 2 is the user's manual for VIPRE and its auxiliary programs. It presents input data requirements and sample problems. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. A. Naser*

Design and Testing of Laboratory Gamma-Ray Densitometer for Two-Phase Flow
NP-2819 Final Report (RP248-1); $10.00

This report describes the development of a scanning, narrow-beam gamma-ray densitometer for measuring void profiles during reflood. The design principles, details of construction, and calibration experiments are discussed. The contractor is the University of California at Berkeley. *EPRI Project Manager: Loren Thompson*

Role of Electrochemistry in Causes and Measurement of Corrosion in PWR Steam Generators
NP-2962 Final Report (RPS191-2); $11.50

This report is primarily a digest of recent work examining the possible uses of electrochemical test methods in monitoring corrosion of the engineering alloys in PWR steam generators. The general principles of electrochemistry as applied to corrosion are presented. The contractor is D. A. Jones. *EPRI Project Manager: J. P. N. Paine*

Investigation of Phosphate-Sludge Interactions
NP-2963 Final Report (RPS158-1); $13.00

This report documents a study of the interactions between sodium phosphate and artificial steam generator sludge or sludge constituents. It includes the results of tests conducted to determine the effect of temperature on the initiation of these interactions. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. P. N. Paine*

Weld Residual Stress Redistribution Near Growing Cracks
NP-2964 Final Report (RP603-3); $11.50

This report presents a numerical analysis of intergranular stress corrosion cracking in a residual stress field of the heat-affected zone of a girth-butt weld. A complete circumferential crack growing radially outward in a 10-cm schedule 80 recirculation line was modeled; the elastic properties of BWR type-304 stainless steel were used. The results show that the axial extent of the initial residual stress field has little influence on stress intensification and crack arrest for an extent greater than three pipe wall thicknesses. The contractor is Science Applications, Inc. *EPRI Project Managers: R. E. Nickell and D. M. Norris*

Main Coolant Pump Shaft Seal Guidelines
NP-2965 Final Report (RP1556-1); Vol. 1, $11.50; Vol. 2, $10.00; Vol. 3, $8.50

This report presents information, guidelines, and recommendations developed in EPRI studies of main coolant pump shaft seal failures in nuclear power plants. This work was directed toward improving pump availability. Volume 1 presents maintenance manual guidelines for pump shaft seals, Volume 2 operational guidelines, and Volume 3 specification guidelines. The contractor is Borg-Warner Corp. *EPRI Project Manager: F. E. Gelhaus*

Examination of Mechanical Snubbers From TMI-2
NP-2966 Final Report (RP1544-2); $13.00

This report describes the testing and examination of five mechanical snubbers removed from the reactor coolant systems in TMI-2 about three years after the accident. It focuses on four snubbers from the decay heat removal line, which showed evidence of severe overloading in both tension and compression. Possible causes of the overloading are outlined. The contractor is International Energy Associates, Ltd. *EPRI Project Manager: R. K. Winkleblack*

Evaluation of Surrogate Boilers for Steam Generators
NP-2967 Final Report (RPS111-2); $10.00

This report examines surrogate boilers—model boilers that could operate in parallel with a utility steam generator to permit periodic inspection for prototypical corrosion damage. The potential benefits of such boilers are described, as well as several conceptual boiler design alternatives. Costs for fabricating such systems are estimated. The contractor is NWT Corp. *EPRI Project Manager: M. J. Angwin*

Primary-Side Deposits on PWR Steam Generator Tubes
NP-2968 Interim Report (RP825-2); $11.50

Analyses were conducted to determine (1) the chemical nature of oxide deposits on the primary side of steam generator tubes, and (2) the radioisotopes incorporated in those deposits. Radiochemical, chemical, scanning electron microscope, and energy dispersive X-ray techniques were used in analyzing tube samples from eight nuclear power plants. Also, in-core crud data were compared with values calculated by a mathematical activity transport model. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. A. Shaw*

Hydrazine Usage for Corrosion Control in PWR Plants With Powdered-Resin Condensate Polishers
NP-2969 Final Report (RPS132-8); $8.50

This report documents testing performed at North Anna-2 to obtain data for determining the optimal amount of hydrazine to use—and the optimal injection point—for oxygen control in PWR units with condensate polishing demineralizers. Conclusions and recommendations are presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Coit*

Residual Stresses in LP Turbine Disks
NP-2970 Final Report (RP1398-8); $8.50

Bulk and residual stresses were determined for low-pressure turbine disks retired from service. Bulk stresses were measured on four disks by the sectioning method, and surface residual stresses were measured on nine disks by the X-ray diffraction technique. The results confirm that both bulk and residual stresses are generally compressive. The contractor is Southwest Research Institute. *EPRI Project Manager: M. J. Kolar*

On-Line Use of Chelants in Nuclear Steam Generators: Feasibility Study
NP-2973 Final Report (RPS166-1); $17.50

This report describes a test program to determine the feasibility of the on-line application of chelants to stop or prevent denting in nuclear steam generators. Tests involving a recommended chelant are described, and the applicability of the results to the field situation is discussed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Secondary Water Chemistry at Millstone-2
NP-2974 Topical Report (RPS170-1); $13.00

This report summarizes secondary-system chemistry and steam generator corrosion observations at the Millstone-2 PWR. A review of plant design characteristics, construction materials, and historical water chemistry performance is included. The contractor is NWT Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Review of Condensate Demineralizer Regeneration Procedures

NP-2975 Topical Report (RPS167-1); $10.00

The performance of deep-bed demineralizers for sodium chloride removal from condensate was evaluated in the laboratory for several different regeneration procedures. Sodium and chloride removal efficiency, sulfate throw, and resin analysis results are presented. The report includes condensate polisher design and operating guidelines that emphasize good resin separation—identified as the factor responsible for positive laboratory results. The contractor is NWT Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Chemical Cleaning Solvent and Process Testing

NP-2976 Final Report (RPS127-1); $23.50

This report documents laboratory and pilot plant investigations conducted to develop and qualify chemical cleaning solvents, procedures, analysis methods, and monitoring techniques to safely remove magnetite, copper, and copper oxide sludges from the secondary side of nuclear steam generators. The work included candidate solvent screening and optimization testing, process monitoring technology development, and tubesheet crevice side-effects testing and evaluation. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. S. Welty, Jr.*

Evaluation of Secondary-System Layup and Cleanup Practices and Processes

NP-2977 Final Report (RPS113-1); $13.00

A study of PWR secondary-system layup and cleanup practices was undertaken to evaluate current and proposed methods of corrosion-product control associated with extended plant outages. The report describes a field survey of 14 representative PWR plants, an extensive literature search, and an evaluation of corrosion-product transport data. Recommendations for layup and cleanup processes are presented, along with system design information. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. S. Welty, Jr.*

State-of-the-Art Evaluation of Condensate Polisher Performance

NP-2978 Final Report (RPS163-1); $29.50

This report describes a detailed survey conducted at 142 operating power plants to determine the capabilities and limitations of condensate polisher systems. Results indicate that condensate polishers can be (and are being) designed and operated to produce the high-quality feedwater required in today's power plants. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. S. Welty, Jr.*

Diffusion and Hideout in Crevices

NP-2979 Final Report (RPS146-1); $17.50

This report describes work to identify the important variables that control contaminant hideout in (and return from) support plate crevices in steam generators. The work entailed a literature review and the estimation of diffusion coefficients for electrolytes in hot water; an experimental study of diffusion rates through simulated crevice packing; a study of contaminant hideout rates as a function of applied heat flux; and the development of a mathematical model. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. E. Shoemaker*

Condensate Polisher Resin Leakage Quantification and Resin Transport Studies

NP-2981 Topical Report (RPS163-1); $20.50

A study was conducted at nine operating PWR power plants to quantify the resin released to the secondary loop from the condensate polisher systems and to determine resin transport throughout the secondary loop. The results indicate that both the powdered-resin and deep-bed polisher systems release some resin; the quantity is largely a function of flow transients on an individual polisher vessel. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. S. Welty, Jr.*

Steam Generator Chemical Cleaning Demonstration Test No. 3 in a Pot Boiler

NP-2983 Topical Report (RPS128-1); $14.50

This project is part of an effort to develop a process for chemically removing corrosion products from the secondary side of PWR steam generators. In this report the demonstration testing of one process in a four-tube boiler is summarized. The results indicate that corrosion products generated under prototypical conditions can be effectively removed with generally acceptable corrosion to steam generator construction materials. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: C. S. Welty, Jr.*

Evaluation of Techniques to Predict Flow-Induced Tube Vibrations in a Preheat Steam Generator

NP-2986 Topical Report (RPS154-2); $13.00

This report presents a mathematical modeling methodology for combining steam generator geometry and operating conditions with structural and fluid dynamics in order to predict the location and severity of flow-induced tube vibration damage in a preheat generator. The three-step mathematical technique is described, and predictions are compared with laboratory data trends and field observations of damage. The contractor is Jaycor. *EPRI Project Manager: C. L. Williams*

Chemical Cleaning Process Evaluation: Westinghouse Steam Generators

NP-2987 Final Report (RPS150-3); $14.50

A generic chemical cleaning process for the secondary side of PWR steam generators has been developed. In this project, that development work was evaluated to determine the applicability of the process to Westinghouse steam generators. Recommendations are made regarding methods for transferring the generic process to a plant-specific application. Chemical cleaning corrosion guidelines for the construction materials in Westinghouse steam generators are also presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Ultrasonic Enhancement of Chemical Cleaning of Steam Generators

NP-2997 Final Report (RPS185-1); $23.50

The use of ultrasound to enhance the chemical cleaning of steam generator tube support plate crevices was investigated. The effort focused on the coupling of transducers to the wrapper plate, the transmission of sound through the tube bundle, and the determination of cavitation threshold levels. The testing demonstrated that ultrasonics is an effective means of enhancing crevice cleaning if sound levels sufficient to cause cavitation can be transmitted to the crevices. The contractor is Anco Engineers, Inc. *EPRI Project Manager: C. S. Welty, Jr.*

Steam Generator U-Bend Eddy-Current NDE

NP-3010 Final Report (RPS202-1); $11.50

This project addressed the problem of inspecting row 1 U-bends in Westinghouse Series 51 steam generators. It investigated the use of conventional eddy-current inspection data to estimate tube ovality in the opposite-side transition region. The test results corroborate earlier results, which found no discernible correlation between the eddy-current inspection signal and tube ovality. The project also investigated the pancake array coil probe as a means of improving primary-side crack detection in the U-bend region. This coil proved superior to the conventional bobbin coil probe. The contractor is J. A. Jones Applied Research Co. *EPRI Project Manager: S. T. Oldberg*

Tube-to-Tubesheet Joint Test

NP-3013 Final Report (RPS119-2); Vol. 1, $13.00; Vol. 2, $25.00

This report documents the development of an optimal and qualified flushing procedure for removing concentrated chemical solutions from steam generator tubesheet crevices. Volume 1 describes testing that examined crevice concentration and flushing; it also covers tubesheet joint thermal and hydraulic testing. Volume 2 presents data from five tests: bare tube, concentric crevice, eccentric crevice, partially rolled joint hideout, and magnetite injection. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: D. A. Steininger*

INFORMATION SERVICES

Research Results and Applications

RA-2732-SR; $15.00

This report presents 70 examples of EPRI research that have been beneficially adopted by electric utilities, have interested suppliers, or have extended and improved original products. It also describes 115 products ready for utility, vendor, manufacturer, or architect-engineer application. Examples cover fuel processing, electric power generation, transmission and distribution, energy storage and management, energy analysis, and environmental assessment and control. *EPRI Program Manager: W. H. Seden*

EPRI Research and Development Projects

TI-3000-SR Special Report; $5.00

This report lists all EPRI research projects and organizes them according to technical division, department, and program. For recently authorized projects and for ongoing projects, the research objectives are described, contractors are identified, and reports are listed. *EPRI Contact: Emily Breese*

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