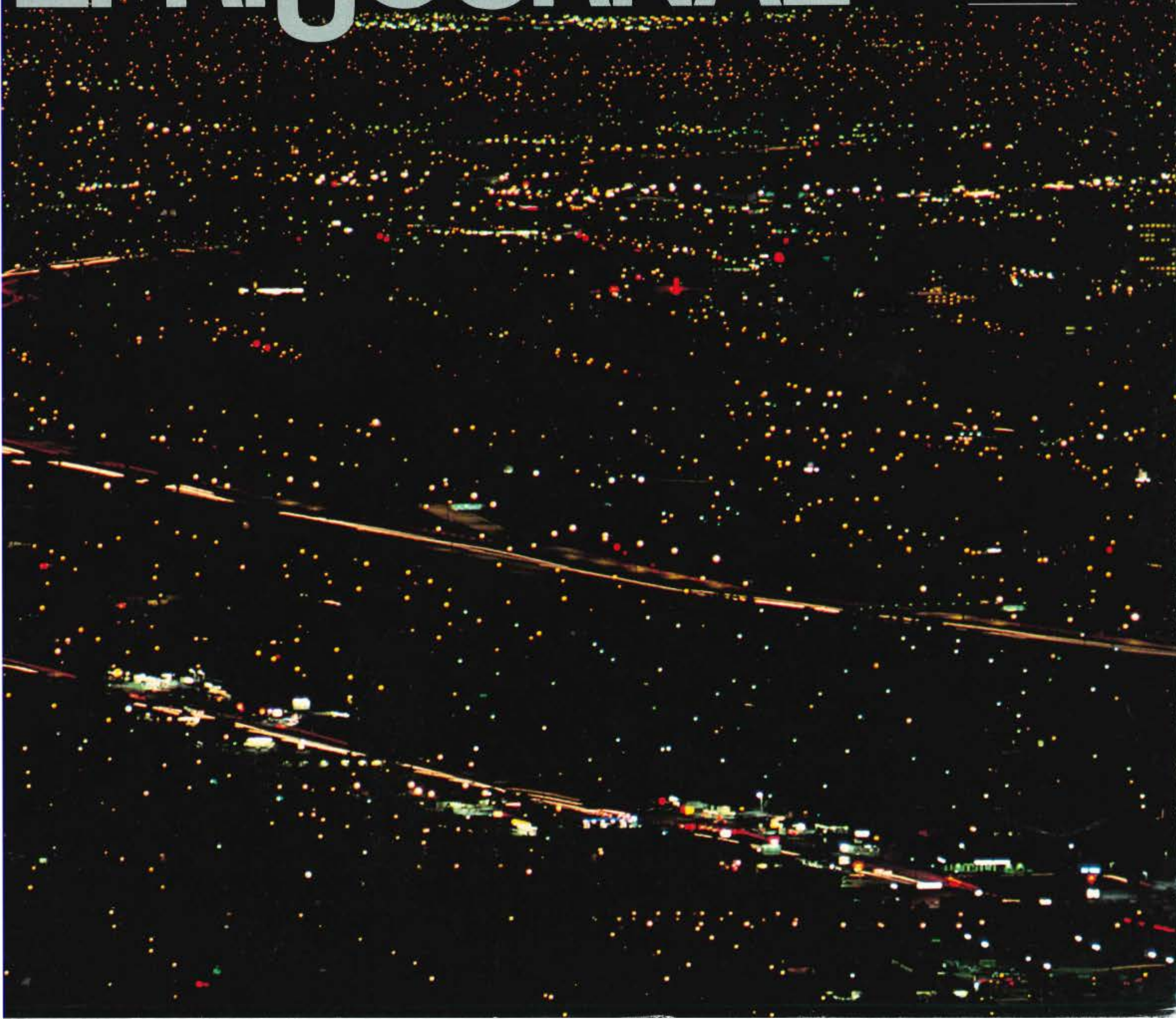
Power Grid Stability

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

NOVEMBER
1982



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

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

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Cover: Keeping today's vast interconnected networks stable under changing conditions is a major challenge to planners of power systems.

EPRI JOURNAL

Volume 7, Number 9 November 1982

Modeling for System Reliability

Reliability of a turbine, a boiler, or a transmission line is of great concern to a utility, but the customer is unlikely to be aware of such problems as long as the power system as a whole provides electricity consistently. Reliability of the system is the bottom line for the consumer. As the backbone of our highly industrialized nation, good power system reliability has allowed us to enjoy one of the highest standards of living in the world. However, planning and operating this system is a major challenge—the North American electric power production, transmission, and distribution system is the largest, most complex mechanism ever built. Planners must make decisions on the size, type, and timing of generation and transmission additions. Operators must select the optimal strategies for generation dispatch and exercise the operating precautions required for system security. All the pieces of the huge power system engineering puzzle must be put together to provide customers with reliable service at the lowest possible cost.

The study of power system stability—one aspect of reliability—is the search to determine whether the system will "stay together" not only under normal operating conditions but also after such disturbances as short circuits or loss of a generating plant. From a security viewpoint, if an area is importing large quantities of power because of generation outages, it is exceedingly important to recognize the threshold at which cascading transmission outages may occur. Failure to recognize these conditions can result in blackouts extending beyond the utility or utilities that were experiencing the capacity shortage.

One way to avoid such problems is to install new equipment, and indeed $27 billion was spent in 1981 on capital additions by investor-owned utilities. But economic, regulatory, and intervenor constraints are making it more and more difficult to place the required facilities in service. For a time at least, the industry is expecting to meet increasing loads and changing conditions essentially with the equipment now on-line; stability will have to be addressed by carefully monitoring the system to keep it within safe operating limits.

With so many variables and system components involved, analysis of even a small power system under only a few sets of conditions can be extremely complex. Unlike many EPRI research programs that concentrate on development of equipment, the Power System Planning and Operations Program has chosen an approach that makes heavy use of computer simulation to model systems under a number of normal and transient conditions. By characterizing their stability limits more accurately, utilities can operate more confidently within realistic margins of safety to the benefit of the customers in their service areas.

The computer-modeling approach offers a high benefit-to-cost ratio. Because large equipment investments are not generally required, research in analytic methods is relatively low in cost; and the value of improving the modeling methods can be substantial. Further, there are many investigators in the industry and at universities who can attack these analytic problems with a high probability of near-term success.

EPRI's research on power system analysis and control is viewed as the primary source of new developments. We will continue to provide advanced but practical methods, data, and computer programs to meet the challenge of power system planning and operations, now and in the future.

Robert H. Iveson

Robert H. Iveson, Manager
Power System Planning and Operations Program
Electrical Systems Division

Authors and Articles

Utility system interconnection allows utilities to share generation and transmission facilities in a way that adds flexibility for all concerned. But it also presents the possibility that problems on one utility system will affect the rest of the network. **Ensuring Power System Stability** (page 6), by science writer John Douglas, reviews what EPRI is doing to guard against network instability, using computers and modeling techniques to break through the barrier of grid size and complexity. Douglas turned to Robert Iveson, James Mitsche, and John Lamont for technical assistance.

Iveson has headed EPRI's Power System Planning and Operations Program since April 1979. Previously with New York State Electric & Gas Corp. for 20 years, he was named supervisor of transmission planning at the New York Power Pool in 1971. Iveson is a 1959 electrical engineering graduate of Rensselaer Polytechnic Institute. He earned an MS in the same field at Syracuse University in 1969.

James Mitsche joined EPRI in June 1980 as a project manager specializing in computer analysis of bulk power system problems. He had been with Consumers Power Co. for three years, primarily in long-range system planning. Mitsche graduated in electrical engineering from Marquette University in 1976 and earned an MS at Purdue University a year later.

John Lamont manages projects for the development of computer programs needed in Electrical Systems Division research. He came to EPRI in July 1978 after five years on the electrical engineering faculty of the University of Texas at Austin. Lamont earlier taught for three years at the University of Southern California and four years at the University of Missouri. He earned a BS in electrical engineering from Missouri at Rolla and an MS and a PhD from Missouri at Columbia.

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Large-scale construction brings in large numbers of construction workers, but boomtowns are not necessarily the result, according to **Plant Construction and Community Stress** (page 14), by Nadine Lihach, *Journal* senior feature writer. With technical guidance from EPRI's Ronald Wyzga, Lihach reviews how EPRI took a systematic look at the impact of power plant construction in 12 case studies and found that the effects were more moderate than expected.

Wyzga is technical manager of environmental risk analysis, Energy Analysis and Environment Division. Wyzga came to EPRI in March 1975 as a project manager in the Health Effects Program, but he concentrated on economic analyses of environmental risks when he became a program manager in 1978. Before joining EPRI, Wyzga worked for four years for the Organisation for Economic Co-operation and Development in Paris; he was also a professor of statistics at the American College there. Still earlier, he was an instructor at the Harvard School of Public Health, where he earned a PhD in biostatistics in 1971. Wyzga also has a BA in mathematics from Harvard College and an MS in statistics from Florida State University.

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Extending the life of a $1500 utility pole might seem insignificant compared with the construction of a multimillion-dollar power plant, but when there are 100 million such poles all over the country, the payoff is significant. **Longer Life for Wood Poles** (page 18), by Jenny Hopkinson, *Journal* feature writer, provides an update on one of EPRI's earliest research endeavors. Technical information came from Robert Tackaberry of the Electrical Systems Division.

Tackaberry has managed research in distribution line materials and hardware since February 1976. He was previously with A. B. Chance Co. for 10 years and before that with Joslyn Manufacturing & Supply Co. for 14 years, working successively in sales, applications, and marketing. Tackaberry graduated from the U.S. Naval Academy and was in the Navy for nine years afterward.

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Advisers supply EPRI management with their varied and valuable perceptions of electric utility R&D needs. Advisers also learn from their experience, and here is one who takes a message back to his own constituency. **Kenneth Randall: Two-Way Communicator** (page 21) is based on an interview of EPRI's Advisory Council chairman by Ralph Whitaker, feature editor of the *Journal.*


Iveson

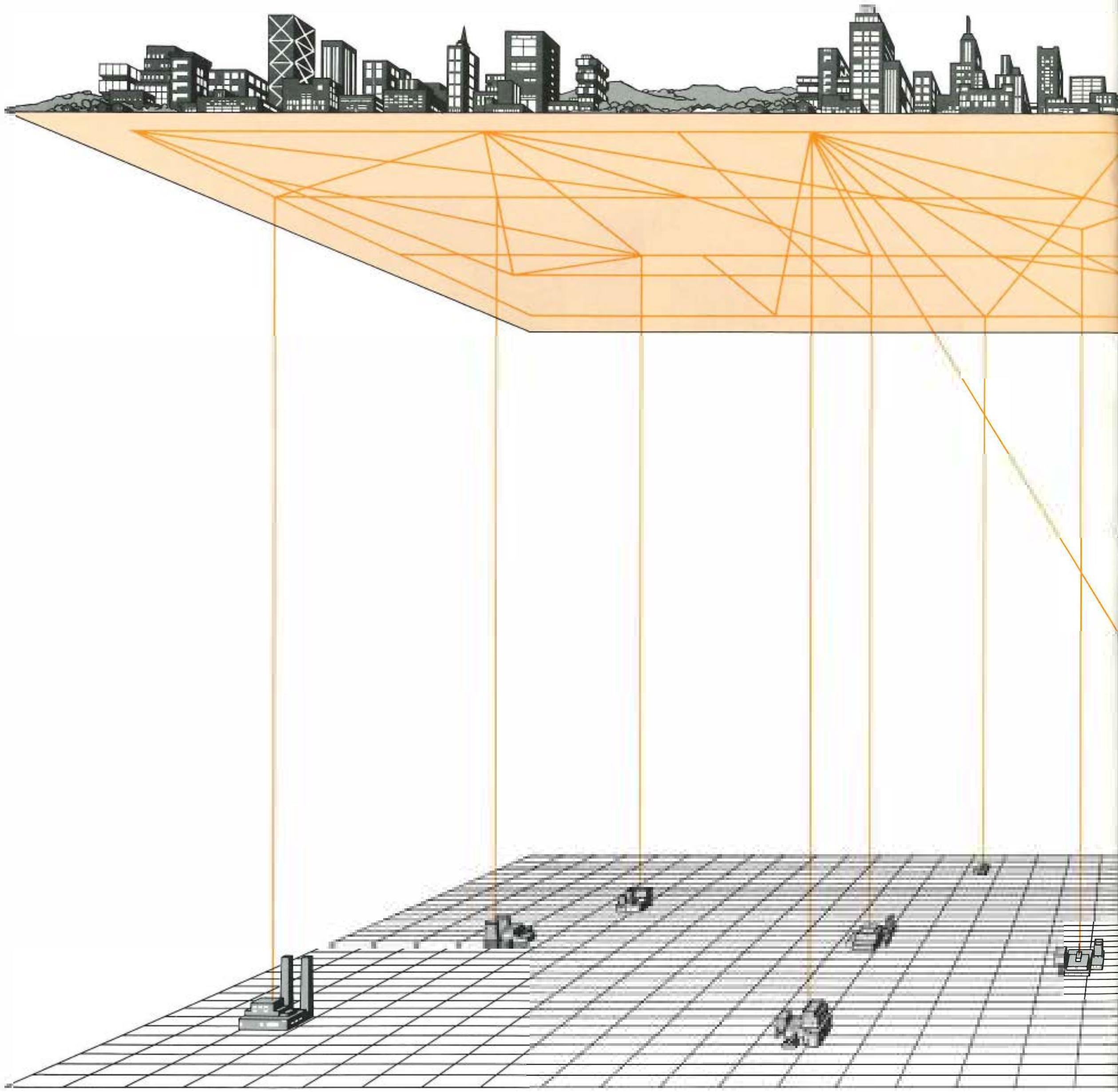

Lamont


Tackaberry


Wyzga

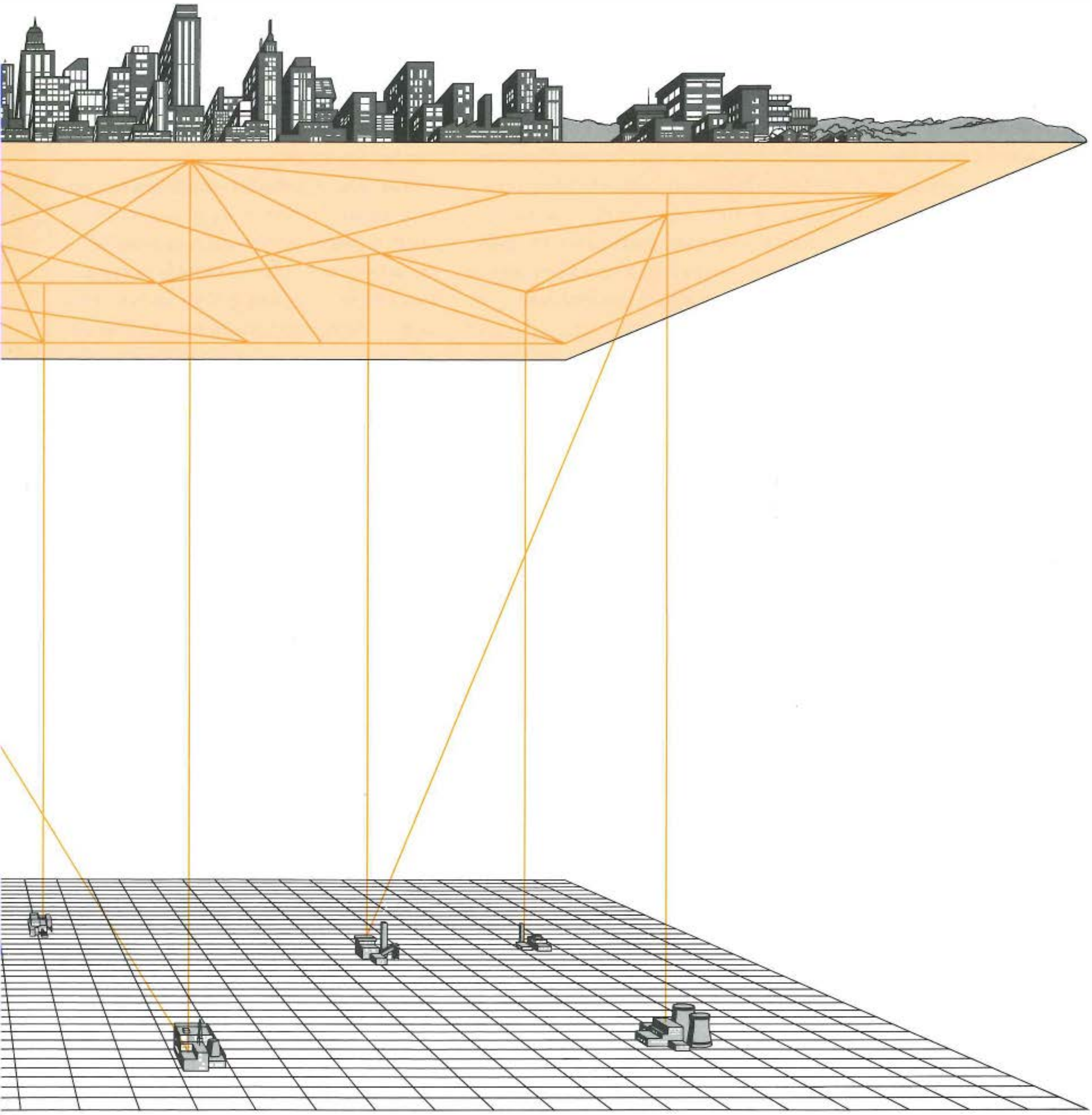

Mitsche

Quality of life in the United States rests in part o
Keeping these systems stable under changing condition



Ensuring Power

ne reliability of vast interconnected power systems.
resents new challenges to the system planner and operator.



System Stability

Since its beginning, the watchword of America's electric power industry has been reliability. Electricity started out as a convenience, but because of its reliability, it rapidly became a driving necessity for an advanced industrial society. Where this element of reliability is missing (as it is in many developing countries today), life retains an uncomfortable edge of uncertainty. For highly electricity-dependent countries like the United States, the value of reliability can best be measured by the enormous economic and social impacts of relatively infrequent interruptions: The short-term estimated cost of the 1977 New York City blackout was $350 million.

The reliability of America's supply of electricity is now being challenged as it has not been since World War II. New generation facilities face unprecedented delays, caused by regulatory and judicial hurdles and by crippling interest rates. New transmission lines are difficult to site. And the need to cut down on the use of oil and gas for electric power production means that electricity must be carried over longer distances from remote baseload power plants, and this produces several system operating problems, one of which is stability. The result is an increasingly complex system of grid interconnections that must operate ever closer to the limits of stability.

The effects are beginning to be felt. In 1979 there were 23 major outages in the United States, each involving load interruption of at least 200 MW, having significant impact on the bulk power network, and affecting a major population center. In 1980 the number of such outages rose to 45. Regions of the country with the most rapid growth are often the hardest hit.

What can be done? A growing number of utilities, working with the Power System Planning and Operations Program at EPRI, are trying to address the problem in essentially two ways. First, power system expansion must be planned with increasingly sophisticated care, using advanced analysis techniques to make sure that the network is capable of providing adequate electricity under expected conditions. Such planning must make allowances for uncertain load forecasts and construction schedules, as well as for the usual facility shutdowns for maintenance or contingencies. Second, new analytic methods must be made available to reliably operate the increasingly complex utility systems. In particular, computer codes are needed that can tell power system operators the changes they can make without adversely affecting system stability.

The triad of reliability

Three aspects of reliability must be given particular emphasis in utility system analysis. The thermal, voltage, and stability limits and properties must be dealt with during all stages—from planning through operation of the grid.

Thermal analysis is relatively easy. Put simply, the transmission lines cannot become so hot they droop into the trees and create a short circuit. (During the series of events that led to the 1977 New York blackout, one set of lines leading into the city was so overloaded because of failures elsewhere that this actually happened.) Fortunately, in many systems thermal analysis falls into a class of what mathematicians call linear problems. To calculate the line rating needed to carry an increased load, one need only make a straight-line extrapolation from previous calculations. If power system analyses were always confined to the study of thermal limits, the engineer's task would be relatively easy.

The second kind of reliability analysis needed for system planning (which deals with voltage limitations) is not so easy. Once the thermal properties of a network have been calculated, engineers must make sure that voltage can be maintained as load is increased. Unfortunately, this is not a linear problem. For normal loads, voltage should be maintained in a narrow range—from about 98% to 102% of rated voltage. However, as loads increase, voltage slowly decreases until a point is reached at which even a small change in load can cause voltage to drop precipitously. Calculating the point at which this happens is fairly complicated, and planners tend to provide a system with flexibility and margin for safety. Such an approach can be expensive.

A similar approach has been taken in dealing with the stability problems that arise in power system planning and operations. Generators must be kept in synchronization, and if their motion begins to change too much, uncontrollable oscillations may be set up in the grid. As long as networks were relatively small, generation plentiful, and transmission lines relatively easy to build, adequate margins of safety could easily be provided. Thus an operator could feel confident that as new generators or loads were brought on-line, there was little chance that the system would suddenly be thrown out of kilter. What has happened to shake that confidence can best be illustrated by the events that took place in the early evening of November 9, 1965.

Lessons from a blackout

Just a little over a year earlier, what was proudly billed as the world's largest interconnected power network had been formed by linking up grids from New York, New England, Ontario, and other parts of the East. The purpose was to share power generation and transmission facilities in a way that could save money for all concerned.

There was also an aspect of increased reliability. If a power company in New York, for example, suddenly had to shut down a major generating facility, it could easily make up the difference by buying power from Ontario. What had not been realized, however, was just how vulnerable the network was to surges of power that might be set off by even a minor equipment failure.

At about 5:15 p.m. it happened. A relay in a power station at Niagara Falls on one of the main transmission lines running north had previously been set to trip if power flow rose high enough to signal a short circuit (a fault). That evening, the load on the circuit reached an unusually high level and was incorrectly interpreted as a fault, so the line disconnected. As power was rerouted to four other northbound lines, they also overloaded and automatically shut off, sending an even greater surge of power southward into New York State.

For any electric power system to remain stable, all its generators must run at exactly the same frequency (60 cycles per second), but when a surge of power backs up into a generator, it begins to speed up. If a generator begins to get too far out of sync with the rest of the system, a protective device automatically disconnects it to prevent permanent damage. Thus, as massive power shifts began to occur within seconds of the initial disconnection (far too quickly to allow human intervention), generators throughout the newly interconnected system were knocked out of service. The result was a cascading blackout that eventually covered most of the northeastern United States and adjacent parts of Canada.

Need for computers

So many different elements must be included in any calculation to see whether a particular network configuration is susceptible to such fluctuations that stability analysis is by far the most challenging problem planners and operators must face to ensure system reliability. "It's not really difficult," says Robert Iveson, EPRI program manager for Power System Planning and Operations, "it's just big. Stability analysis is one of the largest computation problems that exists—like modeling the weather." The typical system being analyzed, according to Iveson, may include as many as 500 generators, and a change in any one of them can affect the rest.

In addition to being nonlinear, stability problems are hard to attack because they require the simultaneous solution of many, many differential equations. Such equations, whose name derives from their use of infinitesimally small changes (differentials) in a system, generally do not have solutions that can be written as a convenient algebraic expression. The alternative is to solve them one small step at a time, and obviously only a computer can attempt this task.

Problems of this magnitude, however, present a formidable challenge to even the best of today's computers. Just modeling one network configuration may take an hour's time on a very large computer and cost more than $1000. Yet utility planners may have to run 200–300 such calculations to make sure the proposed system will remain stable under just the most likely set of future conditions. Ideally, some system operators should also be able to run a few such calculations each day to make sure that anticipated shifts in load and generation will not lead to undesirable excursions.

James Mitsche and John Lamont are the EPRI project managers involved in efforts to develop new computer programs for utilities to use in meeting the challenge of stability analysis. Like Iveson, Mitsche emphasizes that the problem is one of massive calculations, not fundamental conceptual difficulties. "We have to take a systems approach," he explains. "All the parts have to work together as power is transferred among various areas of a network."

The way power is shifted from one generator to another is by advancing the angle between their rotors. Problems arise if that angle becomes so great that the generators drift out of phase and begin to rotate independently. Mitsche likens this coupled motion to the movement of two magnets—one on top of a piece of paper and one beneath. When one is moved slowly, the other will follow. But if one is jerked too quickly, they pull apart.

Calculation of coupling between generators becomes difficult only because a whole electric power network must be considered at once. "We can't just consider a grid to be a wire between a generator and a consumer," Mitsche comments. "With systems and equipment as complex as they are today, networks can become reconfigured so that oscillations start spontaneously."

The response must be twofold. On the one hand, more elaborate and precise contingency analysis models are needed to tell utilities how a particular system configuration will respond to hypothetical events, such as lightning striking a transmission line. On the other hand, much faster quantitative calculations are needed to help monitor system stability and to tell operators when potential problems are developing.

Accounting for regional differences

In preparing these analytic tools, several other complicating factors must also be taken into consideration. Perhaps the most important of these are related to the striking differences that exist between individual utilities and between various regions of the country. Typically, utilities in the East belong to tightly coupled networks. These are characterized by very dense concentrations of generators and loads, using relatively short (50 miles [80 km] or less) transmission lines that are usually designed to remain connected during a system disturbance.

Networks in the West, however, tend to be weakly coupled. That is, generation facilities and loads are widely spread out, transmission lines are often very long, and connections are designed to be broken when problems occur. This enables the disturbances to be contained and not propagate into neighboring utilities, as they did in 1965.

Each type of network faces a different set of problems. Utilities in the West are connected to a 4000-mile (6400-km) ring of transmission lines sometimes called the western doughnut. This means that a generator at a nuclear power station in California must be kept in sync with another a thousand miles away at a hydroelectric facility in Washington State. Keeping different kinds of generators coupled over such distances is difficult to begin with, and as James Mitsche puts it, "Western systems had to be designed with stability foremost in mind." However, as the interconnected network has grown, an unexpected new complication has arisen—spontaneous oscillations that affect the whole "doughnut." The causes of these oscillations and their potential cure remain a subject for considerable study.

Eastern networks were initially considered to be more stable because of their strong coupling. Now, however, that advantage is disappearing. Few major new generation facilities are sited in urban areas, so power must be carried over longer distances to meet the demands of load growth. In New York this means importing more electricity from Canada; in Florida it means carrying power several hundred miles from baseload generators in Georgia and Alabama.

Such long-range transport usually leads to less-expensive electricity for the consumer. Since the oil crisis, it has become increasingly cheaper to ship bulk power over long distances by wire from remote coal, nuclear, and hydroelectric plants than to use local oil- and gas-fired facilities. However, because new transmission facilities are also hard to site, the burden on older lines (which were designed for local supply) is growing. The result in all parts of the United States is an increasing vulnerability to outages caused by system instabilities.

EPRI's response

EPRI has several projects aimed at helping utilities cope with stability problems. Some of the analytic methods involved now push the state of the art of computer modeling. To help explain just how these models work, both Iveson and Mitsche like to talk about the problem of a ball sitting at the bottom of a

UNDERSTANDING STABILITY

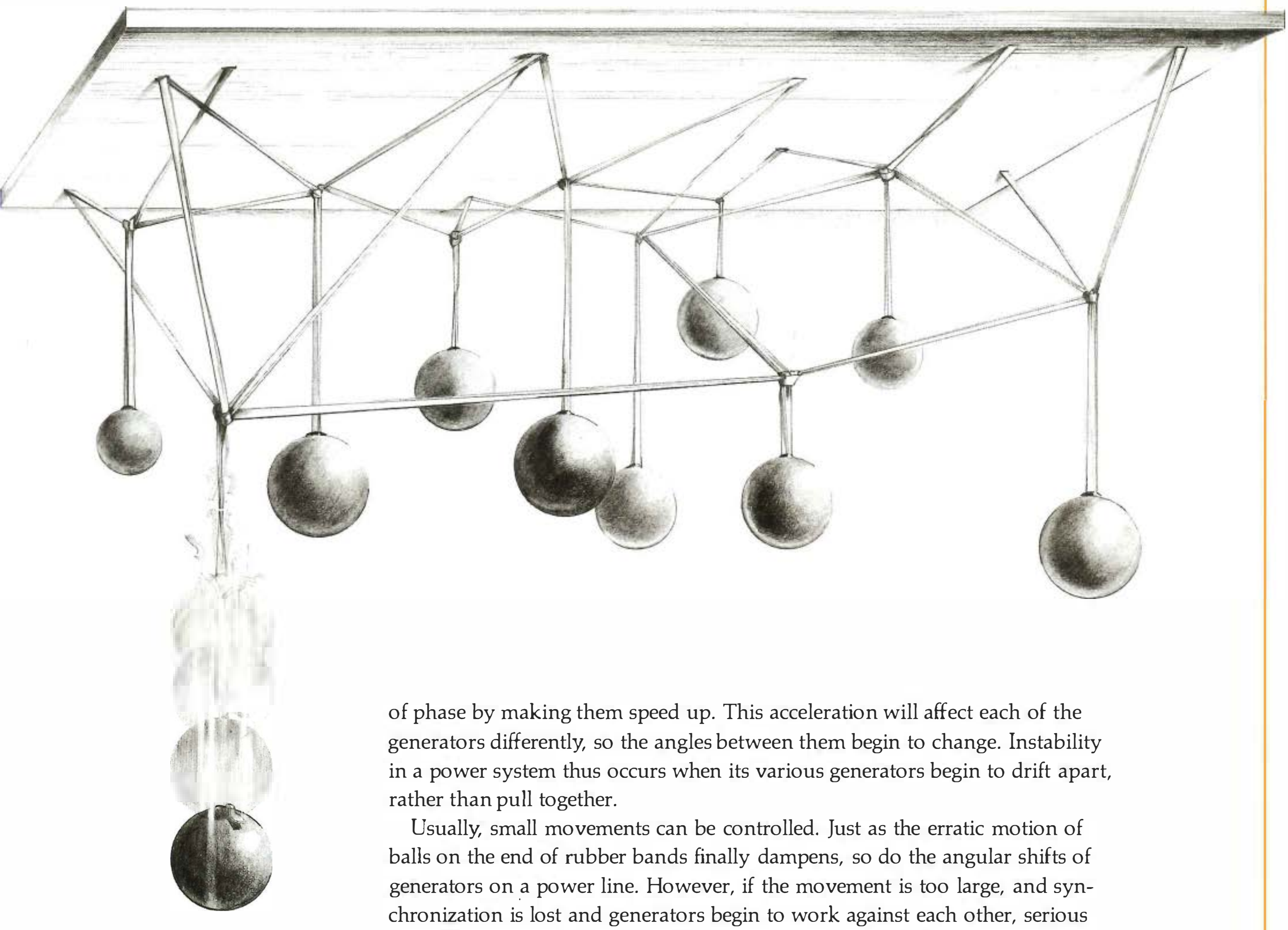
Power systems are extremely complex, and understanding what stability means on such a system can be difficult. A simpler physical model may be used to represent the concept: Suppose that a number of heavy balls of different weights are each suspended by rubber bands from a flat board, and in turn connected to one another by horizontal rubber bands. The balls stretch the bands in proportion to their weight, their relative position, and the network of interconnection. As long as the balls are not too heavy, no rubber bands will stretch beyond their breaking point, and when motion ceases, there is said to be a static stable system.

Now cut one of the stout rubber bands holding one of the heavier balls. All the balls begin to bounce, stretching each of the bands, as the system attempts to recover from the disturbance. If one ball should stretch its bands beyond the breaking point and fall to the floor, the system is said to be unstable. And because the system is now weaker, a chain reaction of breaking bands and falling balls can result—the entire system collapses. If, on the other hand, a system has the inherent strength to survive the original disturbance and settle into a new steady state, it is referred to as a transiently stable system.

Stability in a power grid has several similarities to the system just described. Instead of balls, we have generators, perhaps hundreds of them, their power output analogous to the weight of the balls; and instead of rubber bands, we have transmission lines. As customer demand or load grows, power output must be increased, and in our analogy, the balls can be said to grow heavier, increasing the downward pull. In electrical systems, the power angle between a given generator and the rest of the system is roughly analogous to the downward pull of the ball. As the pull increases (or the power requirements increase), the angle opens.

The angle a generator makes with the rest of the network is critical in determining how much power it delivers. By increasing the steam flow on a turbine or opening a gate in a hydroelectric plant, one can momentarily increase the speed of a generator rotor and thus widen its power angle. The result is that more power will be sent onto the wires. There are limits, however. For angles beyond 90°, a generator begins to send less power as angles increase, thus moving the generator further out of step with the system, and instability results.

Again suppose a sudden change occurs, say the loss of a power line that cuts a major load out of the system. As the surge of surplus power backs up in the generator (since steam or water is still flowing), it tends to throw generators out



of phase by making them speed up. This acceleration will affect each of the generators differently, so the angles between them begin to change. Instability in a power system thus occurs when its various generators begin to drift apart, rather than pull together.

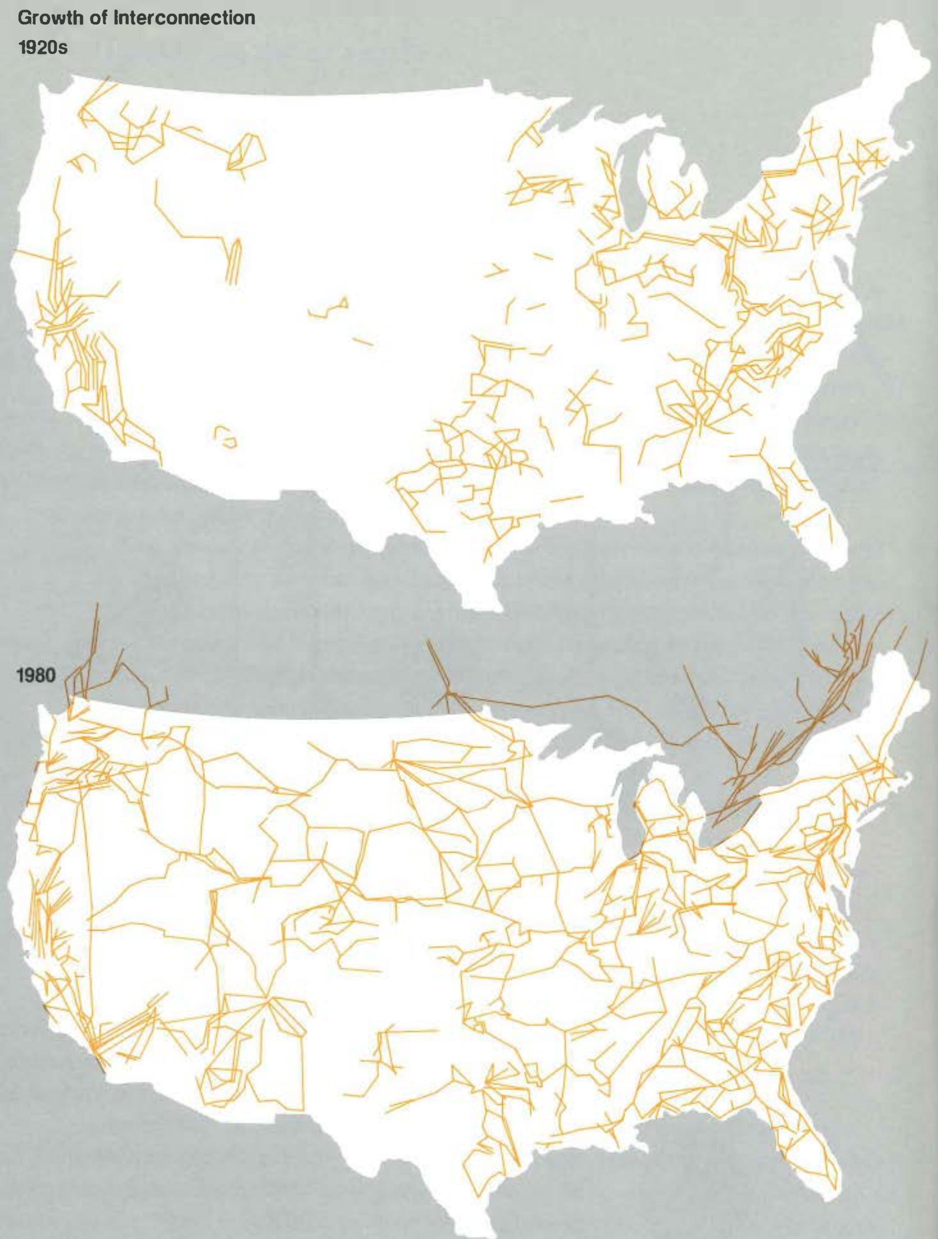
Usually, small movements can be controlled. Just as the erratic motion of balls on the end of rubber bands finally dampens, so do the angular shifts of generators on a power line. However, if the movement is too large, and synchronization is lost and generators begin to work against each other, serious damage can occur. To prevent this, a generator is automatically removed from the line when its power angle grows too large. If too many generators are lost or if the transmission lines are stretched too far, the entire system can be lost and total instability or system collapse occurs. □

hill. Next to the ball is a coiled spring, which, when released, pushes it part way up the hill. The analogy to the problem of electric power network stability is this: Was the initial fault, or shock to the system (represented here by the release of the spring), enough to make the system unstable (in this case, to push the ball over the top of the hill)?

There are two types of calculations that can be used to find a solution to this kind of problem. In the first method, one tries to compute the balance of forces and acceleration for the ball for many little steps up the hill. This is the differential equation approach, which is well established and widely used. Alternatively, one can try to determine the ball's initial energy and how much it needs to reach the crest. This approach, which involves calculating an energy function for the system, is very useful, but it is new and somewhat revolutionary.

The first approach is the subject of a five-part research project to improve a computer program that can analyze large-scale power system disturbances. This program is the outgrowth of an earlier prototype and is called the extended transient/midterm stability program. (Transient instabilities are generally considered to be those that occur less than eight seconds after the fault; midterm instabilities may occur within five minutes.) Features of the new computer program include automatic stepsize selection (up to one second per step) for midterm analysis, an improved model of high-voltage direct current (HVDC) transmission lines, a simplified way of modeling various network components, and advanced methods for carrying out the step-by-step solution called numerical integration.

Also included in this computer program are results from other EPRI projects. To save computation time, part of a very large network can be selected for detailed study, while the rest is simulated by a method called coherency equivalence. And to extend the appli-



In the mid 1920s there was no interconnection of bulk transmission lines, and for all practical purposes, utilities were electrically isolated companies. Interconnection began on a large scale in the 1950s as a means of enhancing system reliability and sharing remotely generated power. This pooling arrangement has continued to grow in the last three decades, greatly increasing the complexity of power networks. It now requires hours of computer time to assess the state of dynamic stability within these systems.

cable range of time for analysis into the region usually reserved for long-term instabilities (5–20 minutes), the program incorporates some features of programs developed in the long-term dynamics research of earlier projects. Shakedown tests of the new program are scheduled to begin this year at six utilities, and the program should be ready for general distribution in 1983.

The alternative computation approach—determining the amount of energy that can jolt a system without having it become unstable—is also pursued. Instead of integrating a large number of differential equations one step at a time, this method calculates a transient energy function to determine how far a system is from instability. Again the process is conceptually simple, but defining this function for a large number of generators and interconnected lines is complex in the extreme. To extend the previous analogy, one is faced with finding out whether the ball has enough energy to surmount *any* hill on a mathematically complex, multidimensional surface.

This energy function approach, if it can be perfected, has a significant advantage over the previous one. Solving differential equations for the state of a network can only determine whether it will be stable for a single event. The solution does not tell operators if they will be able to successfully impose those conditions. Finding that out is called dynamic security analysis.

For example, suppose a power system is in a condition called state A, with a number of generators and transmission lines in operation. Currently available security monitoring methods can tell operators whether state B (with added generators or fewer transmission lines, for instance) will be stable, but it cannot tell them whether instabilities may arise as they take the system from state A to state B. Energy analysis can; as long as the transient energy function of a network remains within calculated limits, the system will be stable.

The computer program being developed can now perform this new type of stability analysis for a 200-bus network. Because of the complexity of this approach, considerable work has to be done to verify it. Therefore, a request for proposal was recently sent out to find a utility that can test the program under realistic conditions.

Several computer programs dealing with specific stability problems are already available. AESOPS1 and AESOPS2 use a third and very powerful analytic technique called frequency domain analysis. This method calculates the potential for setting up spontaneous oscillations in a network. A transient stability diagnostic program (TSDP1) is also available.

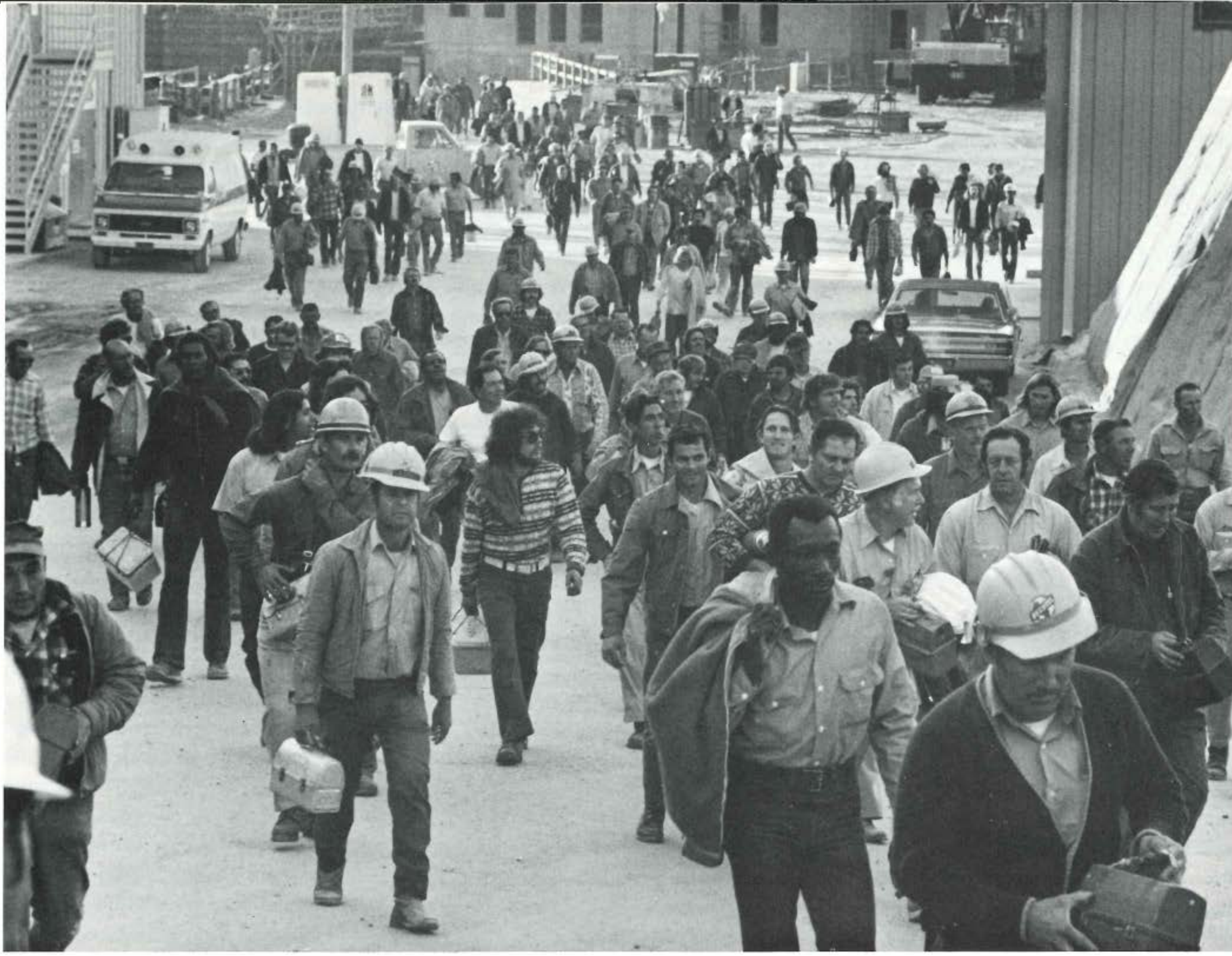
A scoping study is under way to appraise current analytic capabilities in the area of minimizing system separation. Such separations result when instabilities cascade, causing complete system separation. The aim of the study is to identify new research needs on system separation as they can be applied to planning, operation, and analysis of electric power networks.

Greater stability in the future

The effect of this research is likely to be considerable. It may cost several hundred thousand dollars to run a full set of stability analyses for a utility system in anticipation of new equipment additions, more network hookups, or changing conditions. However, the full investment can sometimes be recouped if the need for just one transformer (at $1 million for 1000 MVA) or one mile of high-voltage transmission line (at $750,000 per mile) is eliminated.

Far more important over the long run will be the avoidance of outages themselves. Leaving aside for a moment the overwhelming social costs of a major blackout, revenue losses and restoration costs alone may easily run a utility many times more than the expense of EPRI's entire research effort in this area. Concludes Mitsche, "The power system is being pushed and will be pushed closer to its limits than ever before. The near-term goal of EPRI's Power System Planning and Operations Program is to provide the best possible tools so that electric utility planners and operators can understand and work within these limits." ■

This article was written by John Douglas, science writer. Technical background information was provided by Robert Iveson, James Mitsche, and John Lamont, Electrical Systems Division.



Plant Construction and Community Stress

When crews of construction workers descend on an area for the two or three years it takes to build a new power plant, local communities, governments, and utilities need to know what the socioeconomic impacts are likely to be.

Power plant construction requires power plant construction workers. To build a new plant, many hundreds or even thousands of workers are necessary for periods of two or three years. Workers bring with them their cars, their wages, their need for meals and homes—sometimes even the need for schools and libraries, hospitals and parks. When the localities where workers converge are large enough to absorb the influx, plant construction has little socioeconomic impact. But sometimes, particularly in small, remote towns, the impact can be considerable. Because of the potential that power plants have to affect the communities near where they are built, it is important for utilities to anticipate socioeconomic impacts, and if the impacts are negative, work with communities and their governments to mitigate those effects.

Not long ago

It was only about a decade ago that utilities began to learn about assessing the socioeconomic impacts of power plant construction. Before that time, assessments were done informally and to varying degrees through utility contact with government agencies and local populations. Sometimes a new road was added or a water supply system improved or perhaps a sewage treatment plant built. But mostly, the environmental impacts of power plant construction, either physical or socioeconomic, were not systematically and formally considered.

Then in 1969, the National Environmental Policy Act (NEPA) was passed. NEPA stipulated that major projects involving federal action—such as the granting of a power plant license or a right-of-way permit—had to be accompanied by environmental impact statements. The statements were to include the effects not only on the physical environment but also on the socioeconomic environment. NEPA in effect formalized what had previously been informal socioeconomic assessments. Since this first legislative action, other federal, state, and local regulations have followed, requiring more thorough assessment of the socioeconomic impacts of power plant construction and operation.

The trend toward impact assessment received additional prodding from boomtown experiences of the 1970s. During that time, several notorious boomtowns sprang from the industrialization of areas in the western United States that had been sleepy towns. Development left these towns with social and economic problems, including inadequate housing, crowded schools, traffic congestion, and increased crime. (Similar problems had certainly surfaced in other historical boom periods, but the increased social awareness of the late 1960s and early 1970s helped focus attention on these boomtowns.) While the boomtown development came largely from mineral, oil, and gas exploration and development, the potential dangers of insufficiently planned development could apply to power plant construction as well.

Because of increasing regulation, more and more utilities today are required to file socioeconomic impact assessment reports, as well as take steps to mitigate potential problems. Yet studies of the impacts of large construction projects, such as power plants, have usually been limited to extreme boomtown cases that do not accurately reflect what goes on at most power plant construction sites. Utilities have also lacked a validated forecasting methodology with which to predict accurately what happens when a power plant is built, as well as a systematic, comprehensive data base that could be used to help predict impacts on the basis of past experiences. With the appropriate studies, forecasting techniques, and data bases, utilities can do a better job in their socioeconomic reports, planning, and mitigation efforts.

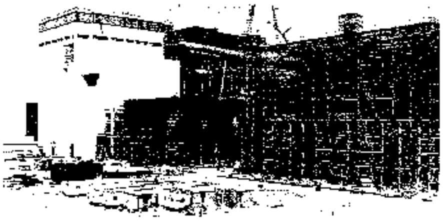
Knowing this, EPRI's Energy Analysis and Environment Division commissioned a study three years ago to acquire a better understanding of the power plant construction process and the socioeconomic impacts it can bring about. The contractors, University of Denver Research Institute and Browne, Bortz & Coddington, both of Denver, Colorado, first conducted a thorough literature search of more than 600 documents to see what was already known about socioeconomic impact assessment. Then they selected 12 recently built power plants and surveyed the actual planning, construction, and early operation phases of each, comparing the outcomes with original predictions. EPRI was searching for a comprehensive information base on the impacts of power plant construction, a better understanding of the extent and nature of these impacts, and an evaluation of the approaches used in socioeconomic impact assessments. "The major issue was finding out what really happens at a plant construction site, as opposed to what we thought would happen," says Division Director René Malès. Although relatively few plants are being built, the question is one that will persist.

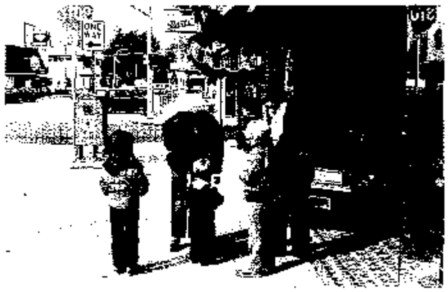
The 12 case study plants were carefully selected to help find the answers: they were scattered throughout the United States, reflecting geographic diversity, urban and rural settings, and a blend of economically stable, growing, and declining areas. Because of a parallel study by NRC involving nuclear plants, the EPRI study's emphasis was on coal-fired power plants, which represented 9 of the 12 case studies.

The mobile worker

The results of the study, compiled early this year, were somewhat surprising—and encouraging—to the utility industry. According to Technical Manager Ronald Wyzga, the impact on communities near the case study plants appeared to be moderate at worst; in general, the impacts were considerably less than had been forecast. In fact, the work forces were fairly nonintrusive. One reason for this was that there were considerably larger, and at times unexpected, indigenous work forces at almost all of the sites, leading to fewer immigrants than expected. For example, the area within a 70-mile radius of Bismarck, North Dakota, has had con-

Some major findings from 12 case studies were that there were larger indigenous work forces than expected at almost all the sites; that workers were willing to commute long distances to their jobs; and that individual workers were on the job for shorter periods of time. This generally meant less disruption than expected for the communities near power plant construction sites because there was a reduced need for permanent housing, schools, and similar services. The study also found that the larger the community, the better it could absorb the effects of construction activity. Smaller, more remote locations sometimes required more planning to avoid negative impacts.





tinuous construction of power plants since 1965. Workers have tended to settle in Bismarck and smaller communities within the area and commute to various power plant projects in the region. At a plant in Minnesota, most workers had prior experience in the construction of taconite plants in northern Minnesota. This bounty of established workers with existing ties meant fewer workers had to move into the construction area.

Another reason why the work force was fairly nonintrusive was that workers proved to be willing to commute considerable distances—60 or more miles, even in northern cold or sunbelt heat—to reach their jobs. Many commuted each day; others commuted weekly, returning home on weekends. Permanent housing was therefore not required to the extent previously believed; most housing used by construction workers consisted of mobile homes, recreational vehicles, and rental units. (Needless to say, the additional traffic caused by plant construction was identified as a significant local impact in all the case studies.)

One more reason behind the moderate work force presence was the shift in construction crafts employed over the life of a construction project. The study found that the initial laborers, carpenters, and concrete workers were ultimately replaced by ironworkers, pipefitters, boilermakers, and electricians. Because specific workers tended to be employed for a much shorter period of time than the length of the project, they were more willing to commute longer distances or to prefer temporary housing; thus they required fewer services of the communities nearest the power plant.

Not only did overall impacts seem more moderate than expected, they also seemed more positive. Increased employment, retail sales, demand for housing, and property tax revenues were all cited by public officials and community leaders as benefits that came with power plant construction. The negative impacts, such as higher housing rents, were usually viewed as temporary annoyances necessary to attain the greater benefits.

Still, the study indicates that not all localities would necessarily savor the positive impacts of power plant construction. Small, remote localities may have a harder time dealing with influxes of workers, so in-depth impact analysis and appropriate mitigation measures may be necessary. A few of the plant sites studied (for example, one in Platte County, Wyoming, and another near St. Johns, Arizona) had the potential for negative impacts, which were fortunately averted by careful planning.

Population in Wheatland, the trade center for agricultural Platte County, increased 37% from 1975 to 1980, the period of plant construction. School enrollment increased 90%, housing stock 33%. Although these changes in a previously declining region provided all the necessary ingredients for a boomtown, most negative impacts were avoided or minimized through cooperative efforts of public and industry officials and by Missouri Basin Power Project's impact assistance. In Arizona, St. Johns's original population of about 1000 reached an estimated 6000 during the peak year of plant construction; but again, through utility and community cooperation, serious socioeconomic impacts were averted. The town's sewer and water systems had to be improved, one school had to be expanded and another built, and a municipal police force had to be established.

Although small, remote localities can have difficulty with power plant construction, not all power plant construction requires mitigation. For example, in the three case study plants near metropolitan areas, economic impacts from power plant construction and operation represented a very small percentage of total economic activity, and no significant positive or negative economic impacts were perceived. These areas clearly had the flexibility to absorb the impacts of plant construction.

Determining when mitigation efforts are required and what they should be is not easily accomplished. As the study showed, one of the most important considerations is the size of the peak construction work force that will create the socioeconomic impacts. "Yet it was not possible to accurately forecast the size of the peak construction forces," says Wyzga. While most assessments considered only one scenario, with a certain number of construction workers on-site for a certain amount of time, such one-shot forecasting could be confounded by many variables. Unusually inhospitable weather, for example, might delay construction; so might an unforeseen labor stoppage. If the materials delivered for plant construction did not arrive on time or failed to meet required standards, the project might also be delayed. If a utility had to wait an unexpectedly long time for a specific permit, the project might also have to wait. Even a utility's financial situation could cause a project to languish; if short on funds, a utility might opt to stretch construction over a longer time.

Whether construction delays were caused by weather, labor, materials, regulation, or finances, the usual solution to the delay was to add extra construction workers at a later date. This sudden rush of labor to make up for lost time could invalidate earlier one-scenario impact assessments based on smaller work force levels. To accommodate uncertainties and avoid unpleasant surprises, the study recommended that multiple scenarios be included in impact assessments if it seems likely that impacts would be significant. One good way to establish multiple scenarios is comprehensive computer models that take into consideration different sources of uncertainties, different startup dates, and varied levels of peak construction.

Future of impact assessment

Besides satisfying today's regulations, there are other reasons why socioeconomic impact assessments may become more important in the future and why utilities have to consider assessments carefully. One reason is the need to maintain high worker productivity. Although data are limited, it can be shown that severe socioeconomic problems, coupled with inadequate mitigation measures, can lead to considerable losses in construction worker productivity. For example, in power plant construction, on-site construction labor usually represents 20–30% of total costs. Therefore, a $1 billion plant could tally up $200–$300 million in construction labor costs. If construction worker commutes are abnormally long, perhaps, or if housing and other services are scarce, the price may be exacted in employee productivity. Even a 10% productivity loss would equal $20–$30 million in additional construction costs.

Similarly, improper socioeconomic assessment procedures and poor mitigation planning can contribute to construction delays, which are especially costly in inflationary times. A $1 billion plant delayed 12 months can cost $100–$150 million more by the time it is built or on-line.

Where federal and state funds are available for energy impact assistance, proper distribution of impact assistance funds depends on more sophisticated assessment of impacts and better identification of mitigation needs. Inadequate handling of potentially negative socioeconomic impacts can also lead to legislative reaction, including more regulation, more rigorous application of existing regulation, and possibly punitive measures, such as higher coal severance or excise taxes.

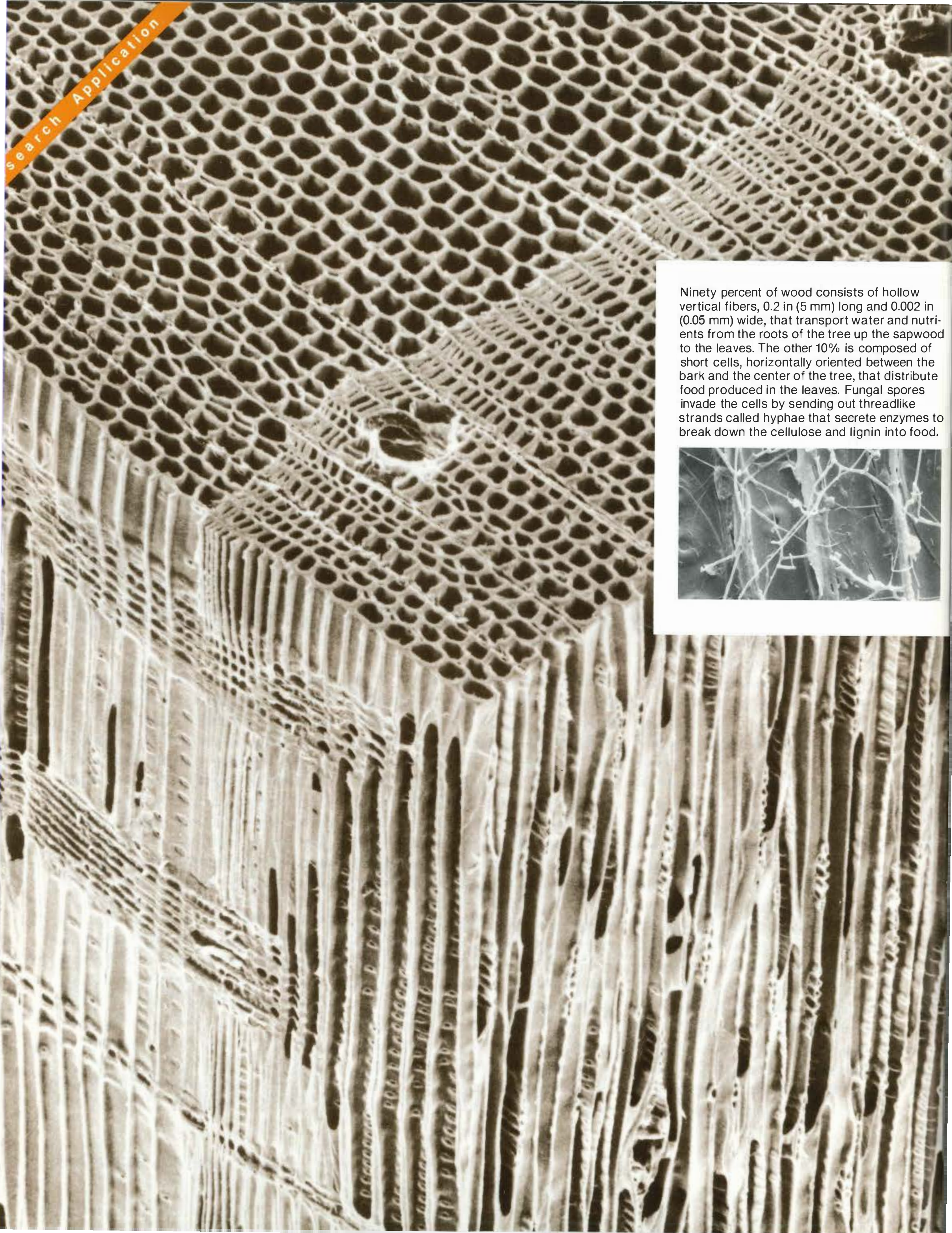
Socioeconomic impact assessment is only the beginning of managing the effects of a new power plant on an area. But impact assessment can set the stage for identification of problems and help develop mitigation programs. "All the problems of power plant construction must eventually be resolved anyway, so they might as well be resolved at the start," concludes Malès. Where positive impacts are identified, these have to be better documented for company articulation before government agencies and the public. With solid impact assessment, plant construction can proceed more smoothly, to the benefit of utility and public alike. ■

Further reading

Socioeconomic Impacts of Power Plants. Final report for RP1226-4, prepared by Denver Research Institute and Browne, Bortz & Coddington, February 1982. EA-2228.

Nuclear Regulatory Commission. *Socioeconomic Impacts of Nuclear Generating Stations.* July 1982. NUREG/CR-2750.

This article was written by Nadine Lihach. Technical background information was provided by Ronald Wyzga, Energy Analysis and Environment Division.



Ninety percent of wood consists of hollow vertical fibers, 0.2 in (5 mm) long and 0.002 in (0.05 mm) wide, that transport water and nutrients from the roots of the tree up the sapwood to the leaves. The other 10% is composed of short cells, horizontally oriented between the bark and the center of the tree, that distribute food produced in the leaves. Fungal spores invade the cells by sending out threadlike strands called hyphae that secrete enzymes to break down the cellulose and lignin into food.

Longer Life for Wood Poles

With 100 million wood poles dotting the landscape, U.S. utilities have a considerable investment to protect from the ravages of wood-devouring fungi. In-service treatment by liquid fumigants may nearly double the life of these poles, and at least 160 utilities are known to be taking advantage of these techniques.

A linesman's climb up a wooden utility pole could be hazardous if the pole's solid outer surface hides a rotten core. Power supply to the public and to industry would be jeopardized if a pole, weakened by decay, toppled in a high wind or a snowstorm. Although utility poles are pressure-treated with chemicals before they go into service as supports for transmission and distribution lines, they are frequently invaded by one or more of 225 species of fungus.

After more than 10 years of studying the wily ways of fungi and such other rogues as carpenter ants and woodpeckers, researchers at Oregon State University, along with cosponsors EPRI and Bonneville Power Administration (BPA), have come up with a wealth of inspection methods and supplemental fumigant treatments that ensure a longer, safer lifetime for poles.

Three fumigants in particular have been found to be superior from the point of view of effectiveness, ease of application, dispersion within the pole, and cost. These volatile chemicals, which were field-tested in EPRI-sponsored research, are Vapam, Vorlex, and chloropicrin. Vapam (sodium N-methyldithiocarbamate) and chloropicrin (trichloronitromethane) are registered with the U.S. Environmental Protection Agency for use on poles. Vorlex (methylisothiocyanate and dichloropropenes) is not yet registered; this means it can only be used experimentally. Vapam is the most widely used and least difficult to handle; however, chloropicrin may remain longer in poles.

The average service life of poles is 15–25 years, but retreatment with fumigants may extend it to 35–40 years. During the decade of research, about 20,000 BPA poles have been retreated. Without such a continuous retreatment program, at least 15,000 poles could require costly replacement because of decay in the coming 10 years. However, by applying the technology developed in this research, BPA estimates it can save $2.2 million per year. The calculation represents the financial advantage in retreating the 15,000 in-service poles instead of having to replace 1500 of them per year for 10 years at a cost of $1500 per pole.

Trees and treatment

In the northwestern United States, Douglas fir and western red cedar predominate as the species suited for utility poles. They were therefore the tree types studied by Oregon State University. With the success of this research, the effort has now been expanded to include southern yellow pine, the species that contributes the majority (80%) of the one hundred million wood poles in utility service in the United States. This work is being carried out in a five-year study by the University of New York at Syracuse.

Utilities always buy poles that have already been treated with preservative. Before this treatment can take place, the wood must meet specifications of length, diameter, and defect limitations set by the American National Standards Institute (ANSI 1972). After being dried either in the open air or in kilns to a moisture content of 30% or less, the poles are placed in cylindrical pressure chambers filled with creosote, pentachlorophenol solution, or copper and arsenic solution. The solution, heated to 190°F (88°C), is forced into the wood under pressure to a depth specified by the American Wood Preservers Association.

However, even though the outer shell (sapwood) of poles is sometimes pierced or kerfed to allow the preservative to sink in more deeply, the natural drying that takes place after the pole is installed opens up cracks, called checks, exposing the pole's untreated core (heartwood) to airborne spores of fungi, as well as to insects.

Fungi

The process of decay begins when fungal spores, microscopic seedlike structures, germinate and produce hyphae, minute threadlike strands that penetrate wood. The hyphae secrete enzymes that dissolve cellulose and lignin, which form the cell walls of trees and the cementing material between them. In this way, the hyphae convert the cellulose and lignin into simpler chemicals that they can use for food.

Because hyphae are so tiny, early fungal attack on wood can usually be detected only by examination under a microscope or by incubating thin core samples of wood on a laboratory culture medium to promote outgrowth of decay fungi.

Later stages of decay can be recognized by discoloration, either staining (brown rot) or bleaching (white rot). In addition, the wood often becomes brittle or crumbly, a condition easily seen in the pick test, when a sliver of wood lifted with a knife breaks at the center rather than detaching as a complete splinter.

The area of the pole near the groundline is the most vulnerable to attack by fungi because of moisture in the soil. Besides moisture, decay fungi require air, a favorable temperature, and food, that is, the wood itself. Wood with a moisture content below 20% is usually safe from fungi, as is wood submerged in water or buried deep in the ground. Temperatures below freezing prevent fungi from growing but do not kill them. Above the freezing point, fungi can grow, multiplying rapidly between 60° and 80°F (16° and 27°C) and slowing down again toward 100°F (38°C).

Pole inspection

Because incipient decay cannot be detected by the unaided eye, researchers are investigating chemicals that color decaying wood or change its electrical and chemical properties so that eventually reliable field detection can be developed. But until such chemicals are perfected, the only available ways to pinpoint incipient decay (as opposed to advanced decay) are microscope examination and culturing of wood cores.

Besides the extensively used practice of extracting cores for lengthy laboratory investigation, less costly methods of testing favored by some inspectors include sounding with a hammer, scraping, probing, and drilling. An experienced inspector can evaluate a pole's state of health by hammering on its surface and listening to the reverberations. A sharp ring means the wood is sound, whereas a dull thud or a hollow echo suggests that rot lurks.

Scraping the surface of the pole can reveal decay, as can probing with a blunt tool or digging around poles to a depth where moisture exceeds the 20% level. Drilling can produce confusing results, as it may penetrate natural soft spots in the wood that could be interpreted as decay. Also, when wood is wet, it drills easily, like rotten wood.

As an essential follow-up to drilling, probing, and coring, holes are plugged with treated dowels and coated with a preservative solution or paste.

Fumigation

When decay is confirmed, Vapam or chloropicrin can be injected into the pole. Alternatively, if decay is superficial, water-soluble arsenicals and fluorides, alone or mixed with creosote or pentachlorophenol, can be brushed on the pole's surface directly or applied to a wrap that is fastened to the pole to a depth of 18 in (457 mm) or more below the groundline.

Although decay fungi will reinvade some Vapam-treated poles in about 5 years, the fungal population remains low for at least 9 years, meaning that retreatment need only take place every 9 years. Because poles treated with chloropicrin or Vorlex have remained virtually free of decay fungi for 8 years, retreatment may be delayed for 10 or more years. In fact, according to Robert Tackaberry, project manager in EPRI's Electrical Systems Division, new studies indicate that decay fungi may be kept at bay for as long as 12 years.

Tackaberry also comments on the Oregon State research, "We now have guidelines for inspection methods, with their various capabilities and limitations. The work done has shown that the fumigants provide effective control as part of the in-service treatment of poles. We anticipate that wider application of this technology will occur in the next few years."

He adds, "Present work on Vorlex indicates that the solid crystals of its active ingredient, methylisothiocyanate, appear to be equally as effective as the liquid, as well as proving to be safer and easier to apply." The crystals are formed into pellets or placed in capsules, inserted in a drilled pole, and crushed when inside the pole to dissipate the chemical.

According to BPA's Peter Lindgren, the utility will continue to fund research into ways of stopping decay in utility poles, even though EPRI's participation is now completed. Funded also by several other utilities, pole suppliers, and wood-treating companies, Oregon State researchers will examine possible starting points of rot in poles, such as fungal infestation of living trees and vulnerability of timber during the air-drying stage, when it lies, shorn of bark, in the wood-treater's yard for up to a year.

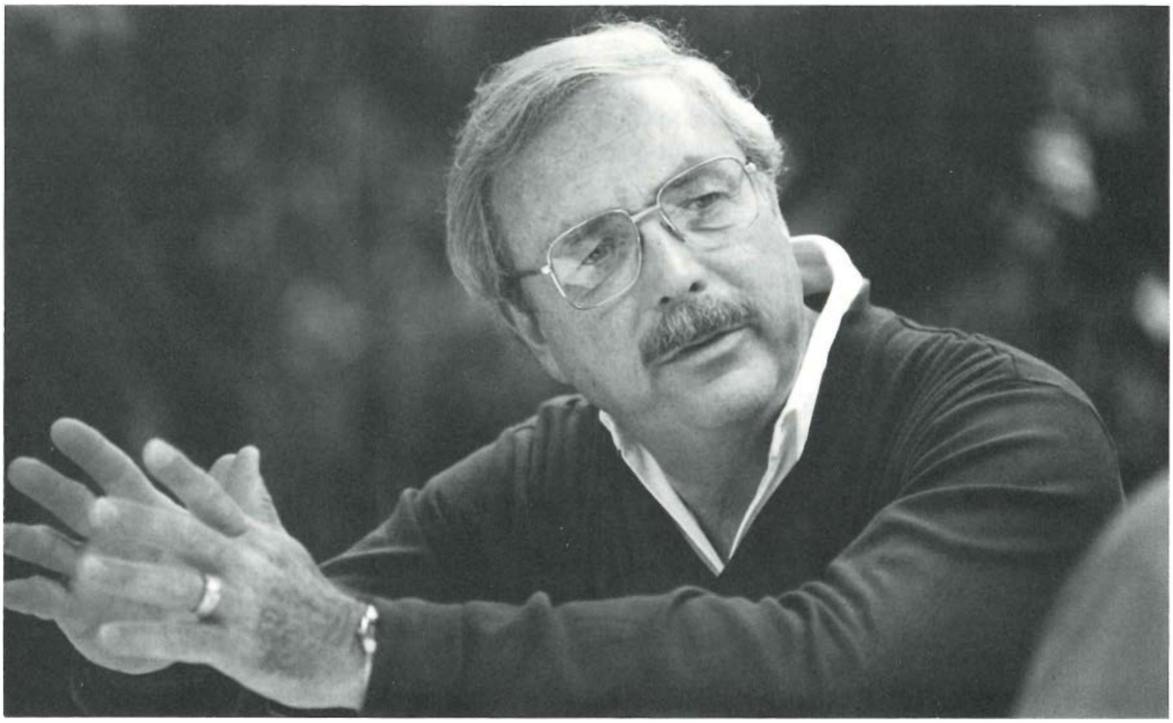
So far, research results on decay and fumigation have helped not only BPA but also more than 160 other electric utilities who are using the fumigants. Although some decay-prone areas in poles, such as seasoning checks and woodpecker holes, will continue to invite the fungal menace, the increasing effort to inspect and fumigate poles on a large scale will ensure safer and more reliable power lines, while eliminating much of the conventional expenditure on replacing decayed poles.

Fumigants can control internal decay in utility poles for at least nine years. The liquid fumigant is poured into holes drilled in the pole. After the holes are plugged with preservative-treated dowel rods, the fumigant moves as a gas throughout the wood to about 8 ft above and below the groundline of the pole to eliminate decay fungi and insects.

This article was written by Jenny Hopkinson. Technical background information was provided by Robert Tackaberry, Electrical Systems Division.

Kenneth Randall: Two-Way Communicator

Advice flows in two directions from the chairman of EPRI's Advisory Council. Institute management hears his convictions as a banker, former economic researcher, and onetime FDIC chairman; bankers and industrialists hear his conclusions as an observer of electric power R&D.



Forecasts come easily in a discussion of energy R&D. For example, "By 2025 we should have very good delivery of electricity—energy of all sorts. The technologies coming along then are very strong. The real problem is for society to last that long. We may not make it to 2025."

Is this really a prediction of economic doomsday? Not when it comes from Kenneth Randall, chairman of EPRI's Advisory Council. Words like *earnest, enthusiastic,* and *optimistic* describe the way he discusses his role today, the career behind it, and the convictions developed along the way. Randall predicts that we will make it through the next 40 years, but at the cost of crash programs and economic penalties to compensate for several more years of piecemeal U.S. energy development.

Now a corporate director and adviser, Randall has been a banker, a bank regulator, and a champion of research in worldwide economic and business practices. The rough road he sees ahead is hardly his preference, either for the electric utility shareholders he represents as a director of Virginia Electric and Power Co. (Vepco) or for the electricity consumers he represents on the EPRI Advisory Council.

At this moment Randall sits in the courtyard of San Diego's Hotel del Coronado in southern California. Wearing a light sweater as he waits for the morning fog to burn away overhead, he waits also for his Advisory Council colleagues to gather for their annual seminar. Joined by several EPRI staff, Board members, and invited speakers—plus a dozen guests from the nation's energy community—the Council will share a three-day discussion agenda titled Energy and the Public Interest. The meetings will be an orientation for new Council members, a tutorial for those in their third or fourth year, but most of all, a common context for all to take into their regular meetings and the occasional work sessions of appointed task groups.

Problems of time and money

The 25 members of the Advisory Council come from many U.S. economic and societal sectors. Appointed by the Board of Directors, they review and comment on EPRI policies and programs—desirability, relevance, balance, timing, and so forth—from their various points of view. Of the Council, Randall says, "I'm encouraged by what I feel is a contribution in a very needed area." And of his own participation since 1979, he adds, "To commit the time that is necessary, you have to believe. And I do.

"I've been on the Vepco board for 11 years now," Randall goes on. "In fact, it was Vepco's chairman who sold me on the Advisory Council, and I've stayed sold. I think it's extremely important to the maintenance of our society that we come to grips with the issues EPRI is encountering."

As Randall sees it, EPRI's day-to-day work may be deeply technical at nearly every turn, but the underlying utility problems and their prospective solutions have widespread influence throughout the United States. "We have major mid-term problems in providing power for jobs to keep our domestic economy healthy. We have major problems of cost competition in world markets. And we're even going to have difficulty keeping the lights on in some areas. These are not just power industry problems; they are extremely important societal issues."

What is not sufficiently realized, Randall emphasizes, is that the electricity component of these problems cannot be overcome quickly. "Society can't say tomorrow that we're going to have 200 new power plants by 1990."

There are already pockets of the United States that show uneven distribution of generating capacity because of population shifts or plant retirements. For the most part, the recession has retarded electricity demand growth, but power companies still suffer from inflation. In such a setting, R&D directed to longer life and lower costs for power systems has Randall's vote. But he limits his comment on EPRI's work mostly to his own professional specialty. "The economic models and projections are quite good," he says. "I have some arguments around the edges, but I like the way EPRI blends ideas and builds cost ranges. Excellent staff, too, I think. They're probably best in intermediate-term research, where technology has been developed and they're working on its commercial application."

The dilemma of research managers and advisers alike shows up in Randall's comments about the scope of EPRI's program. "Where it should be best and isn't at the moment is in long-term basic research. That's been a casualty of the

"Where EPRI should be best and isn't at the moment is in long-term basic research. That's been a casualty of the short-term work needed just to keep utilities alive."

short-term work needed just to keep utilities alive. I don't like it," he adds, "but that has been a reality."

That reality, clearly a problem of available funds and their allocation, evokes its own measured but urgent response from Randall. "Compared with R&D budgets in other countries—indeed, in other U.S. industrial sectors—the electric utilities of the United States are still not making the research commitment necessary to do the job. They're not putting enough bucks into it."

Advisers: credible or expert?

Randall softens his hard conclusion about research funding with an acknowledgment that tradition seemed to call for more R&D responsibility by utility equipment suppliers. He also realizes that the views of utility regulatory commissions are seen as a limiting factor on R&D expenses—how much should be included in electricity rates and how should it be decided?

Channeling public questions and recommendations into EPRI is the official purpose of the Advisory Council, but Randall sees an important communication flow in the other direction. Gaining popular acceptance of the true R&D need is a major Council function, he believes. "We're also a way for the public to learn what is going on and what is needed."

Randall observes also that EPRI management gains confidence from the presence and independence of the Council. "You know, EPRI has not been hesitant to express its viewpoints to us, and that, I think, is an important element of keeping credibility."

Credibility among utility regulatory bodies is especially important, Randall believes, and it is not lost on him that seven state utility commissioners sit on the Advisory Council. "To have regulators among the Council members creates an environment that is critically important. Without them, in my view, the real danger would be the disallowance of rate-based funds coming to EPRI. State commissions just don't always see the local value of a nationwide program."

Randall believes the Council would benefit if more of its members had firsthand familiarity with the electric power industry. He counts himself and Charles Zwick (both of them utility board members) as the only ones in recent years. Asked about the knowledgeability that regulatory commissioners bring to the Council, he responds, "Despite their exposure through the processes of hearings and so on, many of them are lawyers professionally, some with a bit of engineering training, but not with direct experience in the industry."

Randall's remark leads to a strongly felt point from his personal experience. "When I was chairman of the Federal Deposit Insurance Corp.," he goes on, "it was still possible for a banker, which I'd been, to become head of the agency. But today we've created a political environment where, if you have knowledge of the business being regulated, you're excluded."

The issue is conflict of interest, and Randall sharply disagrees with how it is often decided. "The person not trained in the regulated field can do more damage than someone who likes his or her industry a bit too well. I think I was more efficient as a regulator because I knew where the problems were."

Because the pendulum has swung so far, Randall concludes that the Advisory Council is an educational experience for its regulator members. "Exposure to this kind of medium is highly beneficial. I wish it could be broader for more regulators."

Communicating half a lifetime

Randall was with the State Bank of Provo, Utah, even while he was in college dur-

"Compared with R&D budgets in other U.S. industrial sectors, the electric utility industry is still not making the research commitment necessary to do the job."

ing the late 1940s. After military service and graduate school, he managed the bank, becoming its president in 1963, just before President Lyndon Johnson's administration drew him to Washington, D.C., for a six-year FDIC term (five years as chairman).

In 1970 Randall became a director of United Virginia Bankshares, Inc., a bank holding company; a year later he was its president and in 1975, its chairman. From 1976 until last December he was president of The Conference Board, a nonprofit organization for business and economic research supported by the membership subscriptions of companies throughout the world.

Now 55, Randall is an adviser or director of 13 companies, schools, and associations. He is very aware of how the demands on his time have changed. "I started running a bank when I was 27, and I was a chief executive officer until I left The Conference Board. I'm enjoying being counsel, not having to be the focal point in an operating role."

If advisory work calls for any single developed skill, it must be communications, and this is a thread that runs through Randall's career. He began college as a speech major, earning debating scholarships and intending to teach. But Stanford University, his junior-year choice, was swamped with registrants in 1947, so he turned to Brigham Young University, close to home. Randall chose some banking classes at BYU, and communications took hold of his life in a different way. "I fell under the spell of a great, great man, Herald R. Clark, the dean of the College of Commerce, who had written his master's thesis about my grandfather's banking operation." Clark's influence was thorough: Randall graduated in finance and banking, and then went on to earn a master's in economics.

The knack for communicating became particularly useful during Randall's FDIC years, perhaps in part because he was a Republican appointee of a Democratic administration. As he recalls, "The Democrats didn't know what I was and the Republicans treated me with suspicion."

A unique communications opportunity came when Randall joined The Conference Board and began an intensive campaign to build the Board's foreign membership. He says of that time, "The challenge was to make the Board truly international, that is, *non*-national, in its approach. I had to operate as a professional expatriate and try to develop that same objectivity in the staff of The Conference Board."

What was the outcome of Randall's unattached, or detached, approach? "Credibility. It's not easy to develop, but it is one of the most satisfying things I've ever done." Randall's approach was not specific to the affairs of The Conference Board, however. Detachment is one of his valuable skills as an adviser to EPRI, where credibility again is a constant objective.

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Technology and freedom

Economic expansion is a subject in which all U.S. spokesmen today do not have credibility. Yet Randall picks up on a point made by Chauncey Starr, the founding president and now a vice chairman of EPRI. "There's growth going on even when the economy looks flat to individuals. That's because of changes in the makeup of the work force. People have income expectations, according to their ages and educations. Even if those expectations don't change for the next 18 or 20 years, we'll need a minimum of 2.5% annual growth just to accommodate the people already born."

Gaining appreciation of this problem and of electricity's role in the solution is among Randall's professional objectives today. But there is another dimension that bothers him even more.

Going back all the way to the city states of ancient Greece, there have been experiments in representative democracy. "Each one died quickly," Randall points out. "I don't think any went longer than 90 years until the Industrial Revolution. Also, except for brief periods, like when the Spanish found gold in the New World, the standard of living hardly changed at all, anywhere.

"But with the birth of the Industrial Revolution, something essentially different happened: the politician could promise a bigger pie tomorrow," Randall's voice becomes a charged whisper, "and he could deliver it!"

This was at about the same time as the American Revolution, and for Randall there was and is a clear connection. "I think it is extremely important that we create an environment that is positive in growth, as an insurance for human freedom."

To the question of resources, he replies with equal conviction that there is no implied necessity for depleting them ever faster. "The issue really is technology; that's how we magnify our current resources and bring on others." As an example, Randall points to nuclear power, saying that if we could complete the fuel cycle properly (with reprocessing and breeder reactors), we would have a stable, economical primary energy source that would last 3000 to 4000 years. "You know," he concludes ruefully, "there aren't nearly as many problems with technology itself as we seem to see. We're our own worst enemy."

Randall fears that the necessary energy development will come by fits and starts and that rolling blackouts, even electricity rationing, could occur. "We got excited in 1973," he says, "and again in 1979. But we have very short memories. Now we have a lot of oil, so we're complacent."

Recalling the regional effects of railroad strikes and hard winters on utility operations in recent years, Randall reminds us that when electricity has to be selectively turned off, industry is the first to go. The resultant economic disruption is tremendous. "If this happens nationwide, we're going to see crash federal programs in energy, and those won't meet needs the way they should. They can't be well planned, so they're very expensive and they themselves create economic disruption."

Delivering the message

Even without resorting to actual figures, Randall emphasizes economic measures, economic indexes, economic projections, and economic consequences; his evaluation of societal issues is couched in rational terms. But society at large so often responds in nonrational terms, making its choices simply on the basis of attitudes and felt values. How does Randall reconcile this; how does he deal with it in his advisory work?

Randall flatly acknowledges that the nonrational is also the real world. Reconciliation of the rational and nonrational depends on communication, and in this connection he makes a point about language and its use. "Barbara Tuchman has written a new book, *Practicing History,* a book of essays on history; and in one of them she says we must remember that language was created to communicate. If we lose the objective of communicating, then we will have destroyed the capability of language."

To the point of the world's irrationalities, then, Randall says we must accept them, and then we must develop the communication skills—the language—to get our messages across. He knows the process is a two-way street, adding, "If we can develop the technique to deliver our message, we will have listened also."

The past 20 years have been instructive in this regard. Randall believes that U.S. commerce and industry have only recently learned how to listen, and he attributes this to the consumer movement, adding, "So far, I think, we have developed better skills of receiving than of sending."

The requirement is clear, and for Randall it is more important than the discovery of a more efficient photovoltaic cell. Recalling the linkage between productivity and freedom, he puts it this way: "Are the productive elements of our society—industry, commerce, and agriculture—going to find the language that will really deliver their message to the population at large?"

Randall does not know the answer, but he knows what it needs to be and he is ready and able to facilitate the process. ■

This article was written by Ralph Whitaker and is based on an interview with Kenneth Randall.

"Even if personal income expectations don't change for the next 18 or 20 years, we'll need a minimum of 2.5% annual growth just to accommodate the people already born."

Guiding R&D Policy

Four or more times each year, a small group of advisers gather to discuss energy R&D issues. Their advice serves as a guide to DOE on policies, priorities, and programs.

Since its creation, the Department of Energy (DOE) has sought the considered opinions of an independent advisory group, the Energy Research Advisory Board (ERAB), as one of the elements in planning its R&D program and related policy. EPRI President Floyd Culler was appointed to the board this past summer and he emphasizes, "ERAB provides a forum for differing viewpoints between those who perform research and those who apply it." Formed in 1978, ERAB is composed of 24 volunteer experts, representing a broad range of disciplines from universities, industry, state and local government, and public interest groups.

The board's diverse composition, of course, is not by chance. The 1972 Federal Advisory Committee Act provides for public participation in federal advisory council deliberations and requires that any committee membership represent a balance of viewpoints. A comprehensive selection process for ERAB members is therefore undertaken by Thomas Kuehn, ERAB's executive director. "There is a fairly elaborate process of selecting candidates and screening them. We look for well-balanced viewpoints to carry out the charter of the board. It takes about six months to complete the process before candidate recommendations are made to the DOE secretary. All appointments to the board are made directly by the energy secretary," he explains.

ERAB reports to James Edwards, secretary of energy, through Kenneth Davis, deputy secretary. This past year, the board has met twice a quarter to fulfill its responsibility to assist DOE in setting research priorities, guiding and counseling on program directions, and determining if adequate program funding exists. Panels reporting to the board meet more frequently on specific assignments requested by the department, such as reviews of conservation and solar R&D programs. Other specific issues studied or reviewed for the department include the effects of atmospheric carbon dioxide, the acid precipitation programs, and the role of the national laboratories. ERAB also reviews and recommends recipients for two prestigious scientific prizes: the E. O. Lawrence and Enrico Fermi awards. But the board's major activity in the past two years has been to make an assessment of the relationship among various energy technologies and to assess their relative priority for R&D at the federal level.

R&D Priorities

To provide guidance to the department on research priorities, an R&D panel was formed in 1980. In the first stage of this effort, the panel was asked to review the adequacy of the federal government's energy technology base. A report, *R&D Needs in the Department of Energy*, was produced in September 1980 as a result. However, because of the change in administration, the board determined that the question of the balance between R&D programs, especially under budget constraints, warranted another review. Louis Roddis, chairman of ERAB, consulting

engineer and former president of Pennsylvania Electric Co. and Consolidated Edison Co. of New York, Inc., explains that "previously the board prepared reports on each separate technology, but no attempt was made to determine the proper priorities among the energy department's R&D programs. The new administration asked us to do just that."

Consisting of the full board and the only time when an ERAB panel did not use outside experts, a second-phase R&D panel was formed. The panel examined each major DOE R&D program in terms of its technical and economic potential, urgency and lead time required, costs and benefits of federal support, contributions to the energy security of the nation, health and environmental risks, and the appropriate federal role. In addition, questions regarding the appropriate funding levels for electric power supply, fuel supply, conservation, and technology base program areas were addressed. The board also provided guidance on the department's appropriate near-, mid-, and long-term R&D and demonstration plans.

The result of this second review, a report entitled *Federal Energy R&D Priorities,* was prepared in 1981. Along with several other recommendations made by the study was one that high funding priority should be given to acid precipitation and carbon dioxide research. The panel also suggested that DOE provide greater support for nuclear waste isolation R&D, conventional reactor systems and safety, the LMFBR base program, and uranium enrichment R&D. The panel felt that energy conservation and end-use technology research were underfunded relative to supply technologies and therefore should be increased.

Roddis emphasizes that the R&D priorities study required "a lot of work to get unanimity of opinion across the entire board. And we succeeded. This is an important point. We were in unanimous agreement on 47 of the 49 program categories in the energy R&D budget—and by a board with a wide variety of backgrounds. The only two areas of disagreement were the electric and hybrid auto and the Clinch River breeder reactor, not the base breeder program as a whole, which was unanimously supported." Such overall agreement is not often found in an advisory group.

This panel on R&D priorities is ongoing and will continue to assess DOE's technology programs and will make recommendations, when necessary, to the deputy secretary.

Other Panel Reviews

In addition to analyzing the appropriate DOE role for energy R&D, ERAB reviews specific topics. Some past research topics, on which reports have been published, have included studies of fusion energy, solar photovoltaics, geothermal, biomass, and advanced isotope separation.

Topics for panel review may be suggested by the secretary, the deputy secretary, an assistant secretary, or the director of energy research, or they may be initiated by the board itself. Final approval for a subject, however, must be obtained from the deputy secretary. Should the need arise to examine a specific area, a panel is appointed by the ERAB chairman, consisting of several board members whose expertise or interest falls in that area. Outside experts are also asked to participate. As Kuehn explains, "The panel members selected are a combination of ERAB members and experts in the specific field of interest for balance. That way we ensure a meshing of broader and specialized perspectives. The panel is responsible and reports to the board directly, not to the department."

Currently, there are three ERAB panels examining R&D-related issues: the first is assessing the appropriate role and mission of the DOE multiprogram national laboratories; the second is determining the appropriate federal role in energy conservation R&D; and the third is examining prospects for federal solar R&D.

The national laboratory study is of particular interest because DOE has much invested in the future of its nine multiprogram laboratories, which employ about 50,000 scientists and technicians and represent a capital investment of around $25 billion. The laboratories have been criticized for outliving their original mission, competing for work better suited for other research institutions, and expanding at the expense of the nation's universities.

In light of proposed national laboratory budget reductions, the deputy secretary requested that ERAB form a panel to define the specific roles of industry and universities, the scientific and technologic capabilities of the laboratories, DOE's policies and procedures concerning them, and whether they are being used effectively. Culler, who is a member of the national laboratory panel, says, "The ERAB laboratory panel recognizes the unique importance of the laboratories to science and technology in the United States and realizes that they are centers of excellence in many disciplines. Many possess unique experimental equipment of great importance to basic and applied science, and all possess exceptionally experienced scientists and engineers. The national laboratories assist universities as special resources for education and research. We are now trying to match the national laboratories to missions that seem appropriate for current problems and policies, to make them as relevant as possible to other work going on, and to find ways to improve their cost-effectiveness."

Preliminary recommendations from the panel, which are subject to board approval, include the following: that the funding of the laboratories by Congress be on a two-year rather than a one-year basis; that the laboratories be allowed to perform more reimbursable work for state and local governments, industry, and other federal agencies; that lead missions be better defined in terms of major programs; and that the laboratories be encouraged to cooperate more extensively with industry. For example, under appropriate conditions, the laboratories could respond to requests for proposals from industry research groups that have special capabilities in particular areas. The report on the panel's assessment of the national laboratories was presented to the full board for its review in September and was approved for submission to DOE.

Another group whose recommendations will be made to the board in November is the panel on conservation. In October 1981 DOE Deputy Secretary Kenneth Davis requested a review of those energy conservation R&D activities that the federal government should pursue. The question of whether the government as a consumer of energy can effectively conduct an R&D program to improve its own use of conservation technologies is also being addressed. In addition, the panel is evaluating the marketplace and institutional constraints that limit proper price response to improvements in energy efficiency. It is also exploring the means to stimulate the industrial and residential sectors to undertake effective conservation research.

Also directed by the deputy secretary and prompted in part by a congressional request, a panel was formed in March 1982 to examine the appropriate federal role in solar RD&D. Although this topic was briefly addressed in the R&D panel's report on federal energy R&D priorities, the House Committee on Science and Technology had additional questions regarding solar research. These concerns included determining which solar research activities would not be pursued without federal support, which solar programs industry would pick up, how solar budget transitions could be carried out to avoid substantial losses in investments made by the federal government, and what role government should play in long-term solar energy R&D.

Open Discussion

In addition to offering guidance and counsel on specific issues, an advisory group such as ERAB promotes open discussion among the members, who represent many different disciplines. For example, with federal emphasis now directed primarily toward long-term, high-risk energy R&D, industry must increase its support of programs cut by the government and, in some cases, adjust its own R&D priorities. Industry participation on ERAB can provide a useful perspective on industry's research needs. "I would like to be able to reflect the needs and concerns of the electricity consumer and, in turn, the electric generation and distribution companies," states Culler, remarking on his perspective as an industry representative on the board. "I hope, too, that by making available the

ENERGY RESEARCH ADVISORY BOARD

Membership as of January 1983

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Consultant
Charleston, South Carolina

Bennett, Ivan L. (Vice Chairman)
Professor of Medicine
New York University Medical Center

*Ancker-Johnson, Betsy
Vice President, Environmental Activities Staff
General Motors Technology Center

*Baranowski, Frank P.
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Great Falls, Virginia

Branson, Herman R.
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Calvin, Melvin
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*Decker, Gerald L.
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**Fletcher, James C.
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Hitch, Charles
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**Landsberg, Hans H.
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*Linden, Henry R.
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Gas Research Institute

McCormick, William
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American Natural Resources Co.

*Moss, Lawrence I.
Environmental Consultant
Estes Park, Colorado

Pimentel, David
Professor, Department of Entomology
Cornell University

*Pry, Robert H.
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Reichl, Eric
President (Retired)
Conoco Coal Development Co.

Schmitt, Roland W.
Vice President, Corporate R&D
General Electric Co.

*Schriesheim, Alan
General Manager, Engineering
Exxon Research and Engineering Co.

Simpson, John W.
Consultant
Hilton Head, South Carolina

*Smith, Clifford
Manager, Business Development
Bechtel Group, Inc.

Thompson, Grant P.
Senior Associate
Conservation Foundation

Tschinkel, Victoria
Secretary, Department of Environmental Regulation
State of Florida

*New member as of 1/1/83
**Term ends 1/1/83

electric utilities' experience and research efforts, a sound basis for the department's program can emerge, particularly in activities aimed at protecting health and the environment—one that protects appropriately but does not result in unnecessary economic hardship to the consumers of electricity and to the industry that is regulated."

The advice generated from ERAB's diverse membership may not always be in concert with the department's viewpoint. As Chairman Roddis notes, "We try to serve as the technical conscience of the department. And in this role, without consideration of political forces, we try to arrive at what we believe to be a rational program." Kuehn agrees and adds, "An advisory committee is only as useful as its members make it. The agency seeking guidance must be able to understand the idiosyncrasies of an independent advisory body. It has to want third-party advice and be able to accept it, even when contrary to the agency's views." ■

This article was written by Ellie Hollander, Washington Office.

EPRI Manages Worldwide Nuclear Fuel Research

Fuel suppliers and utilities from seven European countries have joined the global research effort.

Earlier this fall, EPRI launched the Nuclear Fuel Industry Research (NFIR) program. The new international effort will provide a single program of generally applicable basic research on nuclear fuel and other core materials and will also supply information on properties and mechanisms considered important to the long-range goals of the nuclear industry.

Membership in NFIR is open to any fuel supplier or utility in the world. At this time, 12 European utilities have joined the program, including Electricité de France, Great Britain's Central Electricity Generating Board, four utilities from West Germany, three from Switzerland, two from Sweden, and one from the Netherlands. The ranks also include one supplier each from Britain, France, West Germany, and Belgium. Additional members are being sought in an attempt to make NFIR a truly worldwide cooperative research effort.

In the United States, members of the cooperative program include Westinghouse Electric Corp., Combustion Engineering, Inc., Babcock & Wilcox Co., and Exxon Nuclear Co., Inc., in addition to EPRI, which represents more than 630 U.S. utilities. EPRI organized the program and will manage it, with guidance provided by a steering committee composed of representatives from each member organization. The combined budget for the first three years of the program is more than $2 million.

The first project to be undertaken will investigate the properties and mechanisms governing Zircaloy corrosion in water. A request for proposals to act as research contractor has been issued to some 20 organizations, and the project is expected to begin later this year. Other candidate projects involve the swelling and fission-product release behavior of uranium dioxide fuels, swelling and gas release behavior of boron carbide control materials, and properties of uranium gadolinium burnable poison ceramics.

John J. Taylor, director of EPRI's Nuclear Power Division, noted that this cooperative approach to generic research problems is likely to be the trend in the future as a result of shrinking R&D budgets in both government and private industry in most countries. ■

Utility Interest in Solar Continues

Solar energy research and development by U.S. electric utilities continued to expand in 1981, according to EPRI's most recent survey. The report reveals that the total number of solar energy activities for 1981 was 12% higher than the number reported in 1980.

A total of 943 solar energy projects was reported by the 236 utilities responding to the current survey, up from 839 projects by the same number of utilities in 1980. Solar energy research by utilities has grown sevenfold since 1975, reflecting a continually expanding commitment to solar R&D. Many of the projects are being carried out by utilities in conjunction with DOE. Because of recent budget cuts, however, DOE's role may be reduced for the next several years.

EPRI Solar Program Manager Edgar

DeMeo notes that much has been learned during the past decade as a result of the "extensive R&D investment by government, industry, and utilities in a wide range of solar and wind activities. As a result of these efforts," he adds, "individual utilities can now begin to focus on those technologies that appear to be most promising for their particular service territories."

Although more than half the projects reported in the survey focus on solar heating and cooling of buildings, the greatest increase in activity is found in other areas, particularly wind power and photovoltaics. The number of wind power projects rose 26%, from 152 in 1980 to 191 in 1981. Photovoltaic projects expanded 42%, from 48 to 68.

The 943 projects represent an investment of $26 million by electric utilities in 1981, and the estimated value of the projects, including past and budgeted spending, is $140 million. The industry also funds solar energy research through contributions to EPRI. In 1981 EPRI's solar power systems budget was $3.4 million; over the next five years EPRI will invest about $30 million in the program.

The 310-page report, *Electric Utility Solar Energy Activities: 1981 Survey,* includes a brief description of each project, summaries of research statistics, and the names and addresses of contacts at each of the 236 utilities. Copies of the report (AP-2516-SR) may be ordered directly from Research Reports Center. Copies are free to EPRI member utilities and are $24 each to others. ■

New Device Measures Appliance Electricity Use

EPRI and Robinton Products, Inc., of Sunnyvale, California, have developed a new system to help utilities track the electricity used in operating household appliances. Called the Electric ARM (appliance research metering), the new system provides the utility with information on which appliances are using the bulk of residential electricity at any given time without wiring them separately. This information will assist utilities in developing effective conservation and load management programs and in preparing load forecasts.

Such detailed customer use histories are important, for example, to a utility considering the application of time-of-use rates or other load management programs. "In the past," explains Edward Beardsworth, EPRI project manager, "this information could only be obtained by separately wiring and installing individual electricity meters on key appliances. Because of the expense and possible inconvenience to the customer, past surveys generally have been limited to total household use rather than appliance-specific use."


The Electric ARM (lower left) collects electricity use information on household appliances, such as this portable heater. These data can help utilities develop effective conservation and load management programs and assist in preparing load forecasts.

The Electric ARM system, however, can reduce cost and customer inconvenience. The system consists of a small box about the size of an electric timer and a receiver that can be located outside the house. An appliance, such as a refrigerator, space heater, or dryer, is plugged into an ordinary electric outlet. Because the box is small, it can be hidden from view and remains out of the customer's way.

Radio signals are sent from the box through household wiring to the receiver, which collects information on electricity use. Although the Electric ARM uses the same frequency to measure the use of all appliances, the data are transmitted in a very sophisticated digital code that distinguishes one appliance from another. Information can be gathered simultaneously on up to eight different appliances.

Appliance-specific data derived from the use of the Electric ARM will help the utility determine whether customers would be able to benefit from time-of-use rates by deferring appliance use to lower-cost time periods. For example, a typical customer has some flexibility in deciding when to use a dryer but not in deciding when a refrigerator will operate. Another advantage of the Electric ARM system is its portable nature—it is easy to install and can be reused in a different location once a survey is completed.

The $588,000 project was cofunded by EPRI and Robinton and took four years to complete. The new system was also laboratory-tested independently by Pacific Gas and Electric Co. and found to be extremely reliable. EPRI is in the process of applying for a patent on the Electric ARM. The system, which has already been ordered by several utilities, is available through Robinton. ■

Strong Interest in AFBC Demonstration

Utilities have responded strongly to EPRI's invitation to join in the design and construction of a 100–200 MW (e) atmospheric fluidized-bed combustion (AFBC) boiler demonstration plant. Nine utilities have proposed commercial AFBC projects, and another 30 have indicated their interest in technical improvement of the AFBC process.

Meetings with the individual utilities have identified five as primary candidates for the AFBC demonstration. These five utilities—The Cleveland Electric Illuminating Co.; Northern States Power Co.; Provo City Power, Department of Utilities; Puget Sound Power & Light Co.; and Tennessee Valley Authority—have started studies to define the project's scope, estimate costs, and begin licensing. Four utilities are reevaluating their sites and schedules—Public Service Co. of Colorado; Duke Power Co.; United Power Association; and Springfield Water, Light, and Power Dept.

The proposed projects cover a wide range of fuels and applications. These include new grass roots plants, building a new plant at an existing plant site, retrofitting a boiler and high-pressure steam turbine (retaining existing low-pressure turbines), retrofitting a boiler (retaining an existing steam turbine), and converting an existing pulverized-coal boiler to fluidized-bed combustion.

EPRI will be evaluating the results of these project development studies and selecting one or more demonstration projects for EPRI participation. The TVA 20-MW AFBC engineering pilot, which started up this June, will provide a significant technical base for these commercial projects. Construction of the selected projects is expected to begin within the next two or three years—but no later than 1985. ■

CALENDAR

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

NOVEMBER

1–4
1982 Joint Symposium on Stationary Combustion NO_x Control
Dallas, Texas
Contact: Michael McElroy (415) 855-2471

2–3
1982 Progress in Nondestructive Evaluation
Charlotte, North Carolina
Contact: Gary Dau (415) 855-2051

2–4
Workshop: Hydro Operation and Maintenance
Atlanta, Georgia
Contact: Charles Sullivan (415) 855-8948

10–12
Seminar-Workshop: ABAQUS–EPGEN
Providence, Rhode Island
Contact: H. T. Tang (415) 855-2012

11–12
Seminar: Cooling Lake Multiple-Use Assessment
Houston, Texas
Contact: Robert Kawaratani (415) 855-2969

14–18
National Seminar: Fuel Cell
Newport Beach, California
Contact: Edward Gillis (415) 855-2542

17–18
2d EPRI Workshop on Water Supply for Electric Energy
Palo Alto, California
Contact: Edward Altouney (415) 855-2626

17–18
Innovative Approaches to Utility System Planning: Modeling Tools
Washington, D.C.
Contact: Virginia Donaldson (415) 855-2746

DECEMBER

6–8
Seminar-Workshop: ABAQUS–EPGEN
Sunnyvale, California
Contact: H. T. Tang (415) 855-2012

6–10
Seminar-Workshop: STEALTH
Washington, D.C.
Contact: H. T. Tang (415) 855-2012

15–17
4th Symposium on Electric Utility Load Forecasting
Dallas, Texas
Contact: Larry Williams (415) 855-2415

FEBRUARY

1–3
Workshop: Hydro Operation and Maintenance
San Francisco, California
Contact: Charles Sullivan (415) 855-8948

15–17
VIPRE–RETRAN Meeting
Charlotte, North Carolina
Contact: Joseph Naser (415) 855-2107

MARCH

22–24
2d Conference on Fabric Filter Technology
Denver, Colorado
Contact: David Eskinazi (415) 855-2918

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

FIELD-TESTING SYNTHETIC FUELS

World economic and political developments during the last decade provided a strong incentive for the development of synthetic liquid fuels technology. Several pilot plants have produced fuels with properties expected to be representative of future synthetic liquids made in production runs. Sufficient fuel was produced to permit full-scale field-testing of utility boiler, gas turbine, and diesel generation units under actual power plant operating conditions. The properties of the coal liquids tested are sufficiently representative of the range of properties expected from production-run coal liquids to provide a broad basis for correlation with laboratory results and for performance prediction with future fuels and generation equipment. Field tests to evaluate methanol and a hydrotreated shale oil residual as utility gas turbine fuels have been completed with favorable results. Methanol and solvent-refined coal (SRC-II) were successfully burned in separate utility boiler tests. A current series of tests, presently in its initial phase, will evaluate performance and emissions and will identify modifications that may be necessary in retrofit or new designs of power generation equipment to burn three types of coal-derived liquids. In addition, transportation, storage, and handling procedures for these fuels, as well as industrial hygiene requirements, will be evaluated as to differences from those for conventional petroleum-based liquid fuels.

In field-testing synthetic liquid fuels made in pilot plants, it is essential that the tests be designed to maximize the useful information gained from the limited amount of fuel available. Candidate test sites and equipment must be identified for characteristics (type, capacity, configuration) that are suitable for testing with limited fuel quantities so their test results can be extrapolated to larger units with a reasonable degree of confidence. The field-testing is directed toward early identification of performance and emissions characteristics for these fuels in various types of power generation equipment, and definition of the kind of retrofit modifications that would be required for existing oil-fired equipment if future conversion to synfuels is considered. Equipment manufacturers are being extensively involved in the synfuel tests so that they can gain first-hand knowledge of possible equipment design modifications associated with liquid synfuel combustion.

The first combustion field tests were conducted with methanol and two early fuels that were available in relatively large quantities—SRC-II liquids and shale oil residue. The SRC-II process is a form of direct liquefaction. The shale oil product was the unconverted residue remaining when shale oil was hydrotreated to make jet fuel as the main product. These fuels have qualitative similarities to the other fuels that will be tested (RP2049 and RP2112). The methanol used in the combustion tests was chemical-grade methanol produced from natural gas reforming rather than from coal liquefaction. It is believed that fuel-grade methanol that might later be available to utilities will not differ significantly from chemical-grade methanol except, possibly, in water content. Methanol to be used as fuel could have extra water (as much as 10–15%) because removal of water results in an added expense, which might not be justified for this application.

The first field test, cosponsored with Consolidated Edison Co. and performed in 1978–1979 (RP1412-2), involved a 4500-bbl burn of SRC-II liquid in a 450,000-lb/h (57-kg/s) coal-capable tangentially fired boiler, producing 1350 psig (9.3 MPa), 955°F (512°C) steam in New York City. The objectives were to evaluate boiler performance and emissions. No. 6 oil was fired to establish baseline data. Tests were run at half, three-quarter, and full load, with greatest emphasis on full load. The boiler was operated both in its normal firing configuration and in a low NO_x configuration.

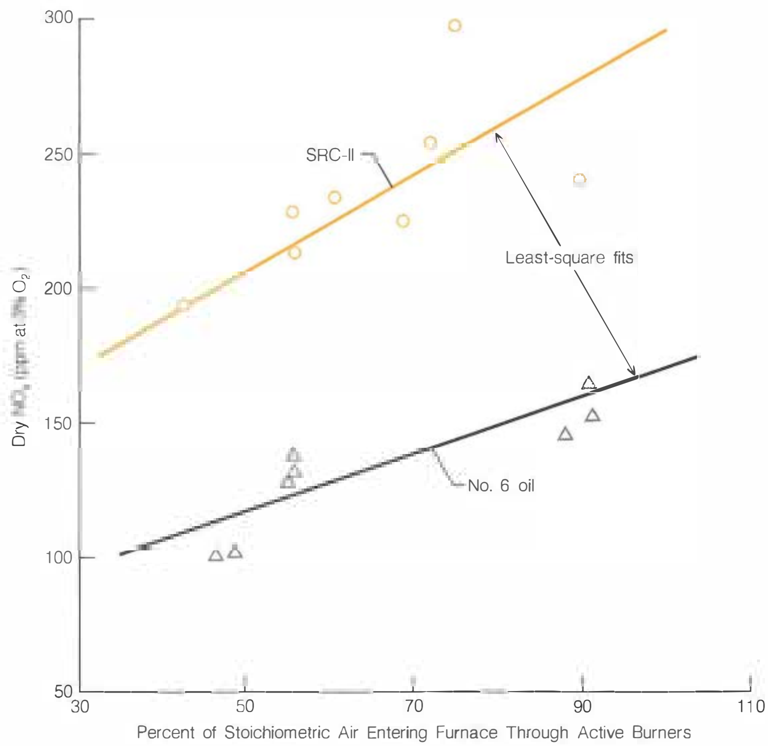
Low NO_x operation represents a condition in which the combustion controls are deliberately adjusted to achieve low NO_x emissions by operating the near-flame zones fuel rich, thereby decreasing the peak flame temperature and the available oxygen. Complete combustion is then achieved by adding sufficient air after the initial combustion products have lost heat to the furnace walls. Figure 1 shows the effect of employing this technique.

Boiler efficiency, calculated by the heat loss method, showed SRC-II combustion efficiency slightly higher (about 1 point at full load) than No. 6, probably because of the lower hydrogen content of the SRC-II, which caused lower water vapor losses in the stack gas. Particulate emissions generated by the SRC-II were less than those from No. 6 oil and were below EPA proposed New Source Performance Standards of 0.03 lb/10^6 Btu under all test conditions.

The second synfuel field test, also cosponsored with Southern California Edison Co. (RP988), consisted of burning approximately 59,700 bbl of chemical-grade methanol in a utility combustion turbine during a 108-day test that accumulated 523 hours of methanol burn time. In this test a 26-MW (e) United Technologies Corp. FT-4 turbogenerator was used at a site near Santa Barbara, California. The test engine, which normally fires natural gas or No. 2 turbine fuel oil, was arranged to permit changeover from No. 2 to methanol while in operation. Water injection capability for NO_x suppression was also available.

The results of this test series indicate that methanol is a technically good utility gas turbine fuel. Combustion hardware was very clean after the test, with almost no visible

Figure 1 Nitric oxide correlation with combustion stoichiometry in a tangentially fired boiler at full-load operations.



soot deposition. Heat rates were about 1.5–3% better for methanol than for No. 2 oil when each fuel was burned without water injection. Water injection increased the distillate fuel heat rate about 1.5%. At all loads, NO_x emissions produced by methanol without water injection were lower than those produced by No. 2 oil with water injection. Figure 2 shows the effect of water injection on NO_x emissions for methanol and Jet-A distillate petroleum fuel.

As the heating value of methanol is only about half that of No. 2 oil, the volumetric capacity of the fuel system to achieve rated load had to be about twice as large. Aside from that, only minor mechanical modifications were necessary, such as replacement of some fuel-wetted elastomers. Lubricity of the methanol was sufficient to prevent damage to existing engine fuel pumps during the short test period. Startups on methanol, as well as fuel crossovers under load, were performed.

Another recent field test, performed by Southern California Edison with EPRI cosponsorship (RP1412-11), involved firing about 10,000 bbl of methanol in a 450,000-lb/h (57-kg/s) front-wall-fired utility boiler at its Highgrove generating station. This Combustion Engineering, Inc., drum-type, nonreheat, balanced-draft boiler has two rows of three steam-atomized Babcock & Wilcox Co. Racer-type burners on the front face, each burner being capable of a heat release of 85×10^6 Btu/h. It produces 1250-psig (8.6-MPa), 950°F (510°C) steam.

The test results show methanol to be an acceptable boiler fuel, with some limitations. Although no problems were encountered in handling and burning the methanol, the storage and pumping facilities must be designed for the higher volumetric requirements (lower heating value) of methanol, its greater volatility, and lower lubricity, compared with No. 2 oil or residual oil.

The overall plant heat rate when burning methanol was 4% higher than for natural gas and 6% higher than for fuel oil. Higher stack losses resulted from firing methanol because of the higher water content of the stack gases and their higher temperature. As methanol has a lower flame luminosity than oil, it produces less radiant heat absorption, thus contributing to higher stack gas temperature. The NO_x emissions generated by methanol were about 62% lower than for natural gas and 58% lower than for fuel oil.

A recently completed field test, cosponsored with Long Island Lighting Co. (RP1691), involved the firing of about 1300 bbl of a hydrotreated Paraho shale oil residual in a 20-MW (e) United Technologies Corp. FT-4A9 combustion turbine generator at Lilco's E. F. Barrett station, Island Park, New York. This test evaluated engine performance, emissions, combustion hardware temperature, and the effect on hot gas path component cleanliness.

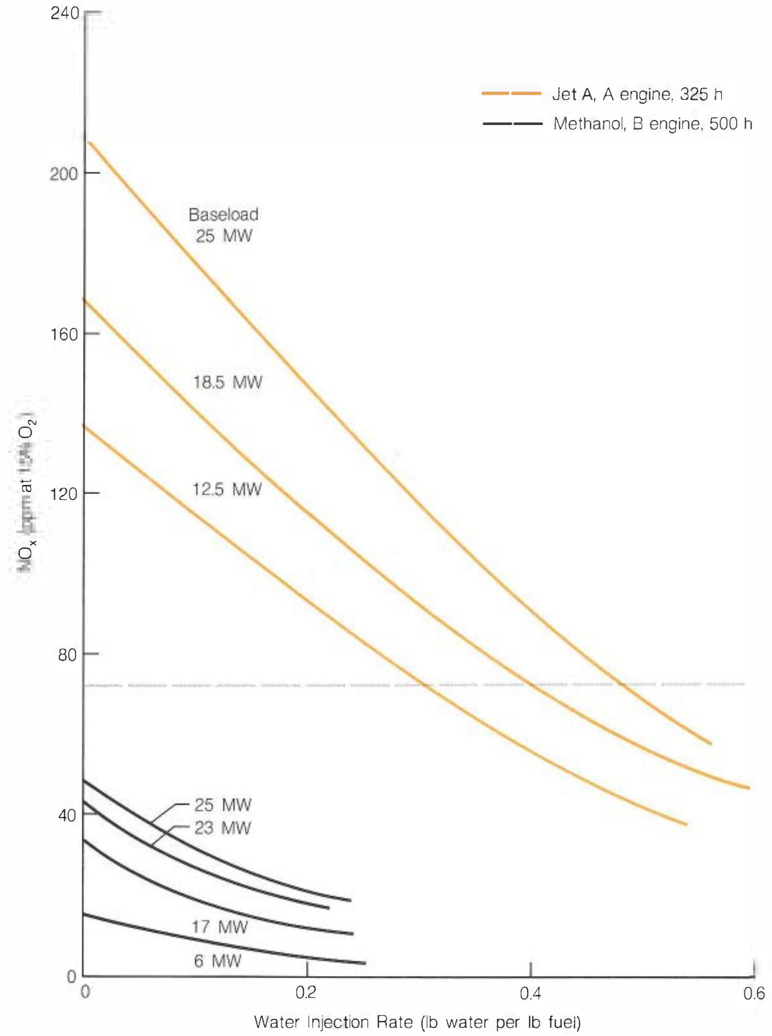
Because of its high pour point and viscosity, the test fuel had to be heated to 150°F (66°C) to effect pumpability and proper fuel nozzle spray pattern. The effect of water injection on NO_x emissions was evaluated by running fuel-water suspensions made with water at fuel temperature. An instrumented combustor can monitored combustor liner metal temperatures, which were 10 to 15°F (6 to 8°C) higher than those produced by No. 2 oil or gas because of the higher flame luminosity of the shale product.

The engine tests were preceded by a single combustor can rig test, using the same instrumented combustor to ensure that safe metal temperatures would not be exceeded on the engine.

Compared with No. 2 oil, there was no detectable difference in the test engine performance during 21.6 hours of operation on the test fuel. The data indicate that smoke, gaseous, and particulate emissions from the test fuel and the No. 2 oil are substantially the same except for NO_x, which is higher from the shale oil residual because of its higher (about 0.5%) fuel-bound nitrogen. The use of a water and fuel mixture (water injection) was successfully demonstrated to reduce the NO_x content in the exhaust gases when the engine was operated on either the test fuel or the No. 2 oil.

A project is under way to evaluate a middle-distillate Exxon Donor Solvent (EDS) coal liquid for suitability as a utility diesel generator fuel (RP2049). Laboratory testing on a 12-cylinder General Electric Co. diesel locomotive engine will precede testing on a 16-cylinder, 360-rpm Cooper Bessemer engine driving a 3.5-MW (e) generator at the Easton Utilities Commission (Easton, Maryland), who is cofunding this project together with the American Public Power Association. Engine

Figure 2 NO_x emissions as a function of water injection rate in a combustion turbine for both methanol and petroleum distillate fuel (Jet A). The dashed line represents the 1982 EPA NO_x limit (75 ppm) for new gas turbines.



performance, emissions, and the factors that must be addressed in handling coal liquids in an operating utility plant environment will be assessed.

A major coal liquids field test, now starting, will evaluate performance, emissions, and fuel-handling characteristics in three operating utility plants, using two full-size boilers and one combustion turbine (RP2112).

In the turbine test, middle-distillate cuts of EDS, H-Coal, and SRC-II will be burned in a 26-MW (e) Westinghouse 251AA gas turbine at the Richmond station of the Philadelphia Electric Co., who is cofunding the test. Testing will take place from November 1982 through February 1983. Southern California Edison is cofunding a test of EDS full-range fuel, using the same 450,000-lb/h (57-kg/s) boiler that was used in the methanol tests under RP1412-11. Test results will be available in mid 1983. In another boiler test, Southern Company Services, Inc., will cofund an evaluation of full-range EDS and SRC-II fuel and a heavy distillate H-Coal at Mississippi Power Co.'s plant Sweatt in Meridian. Test results will be available in late 1983.

The SRC-II fuel to be used in this test program is higher in nitrogen and lower in hydrogen than the H-Coal and Exxon Donor Solvent fuels. All three fuels are higher in nitrogen and lower in hydrogen than comparable petroleum fuels. Off-stoichiometric firing techniques to reduce NO_x emissions without generating smoke will be evaluated with these fuels in the boiler tests. Water injection to reduce NO_x emissions will be included in the turbine tests. *Project Manager: Henry Schreiber*

SOLAR-THERMAL CONVERSION

A number of solar-thermal conversion pilot units have come on-line in the past few months, and a few others will join them in the next year. The EPRI solar-thermal subprogram is involved in efforts to document and disseminate the information and experience gained from these field installations. This year, the first commercial ventures were announced that will take advantage of state and federal tax incentives. More of these ventures may soon be disclosed as a result of a utility-issued opportunity announcement.

Central receiver power towers

On April 12, 1982, the 10-MW (e) solar-thermal pilot plant, called Solar One, achieved turbine roll. This joint DOE-utility project, located in southern California's Mojave Desert, is now well into its two-year test and evaluation phase. The early part of the program is directed toward thoroughly testing the solar receiver and operating the entire plant with the energy produced by the receiver. Southern California Edison Co. (SCE) personnel are operating the plant, and Sandia National Laboratories (Livermore) engineers are conducting the tests. The plant has operated at its rated capacity of 10 MW (net), and preliminary test data show its performance is close to expected values. However, detailed results must await the in-depth performance analysis now in progress.

EPRI is supporting this project by assisting in the documentation of the lessons learned in the construction and acceptance-testing phases (RP2003). A report will be published after the first of the year. Subsequent efforts are expected to include distribution of the results of the extensive testing that is now under way and are expected to continue into late 1984.

The last of the federally funded design studies for repowering existing utility oil- and gas-fueled power generation units are expected to get under way shortly. Three projects, each using a different heat transfer fluid, will be funded through the preliminary design phase.

- El Paso Electric Co. is continuing in the design of a water-steam solar central receiver for its 82-MW (e) Newman Unit 1.

- Arizona Public Service Co. is also continuing with the design of a 60-MW (e) molten salt (a sodium nitrate–potassium nitrate mixture) solar system for Unit 1 of its Saguaro plant.

- Pacific Gas and Electric Co. (PG&E) will design a new 30-MW (e) liquid metal (sodium) solar central receiver plant to work in conjunction with its Moss Landing plant near Monterey, California.

Each of these utility projects is supported by an experienced industry group. It is hoped that one or more of these projects will find the necessary financial support to go forward to a demonstration project, but the future is clouded. Further financial support from the federal government is not expected to be forthcoming, and the continuation of certain energy tax incentives beyond 1985, which might reduce the financial burden of these projects, is also uncertain.

On May 3, 1982, SCE issued a solar program opportunity notice requesting expressions of interest from industry to supply power from solar central receiver power plants. A site in the Mojave Desert area, east of Los Angeles, is proposed by SCE for the first plant; SCE is in the process of obtaining the necessary permits for the site. Again, it is anticipated that a number of the industry proposals will have sufficient merit to justify going forward with one or more studies and, if financing can be obtained, to build one or more solar-thermal central receiver units.

To support the continued development and demonstration of advanced central receiver systems, a group (made up of partners from industries, utilities, DOE, and EPRI) is attempting to get closure for funding a molten salt solar-electric experiment. If successful, this 750-kW (e) complete central receiver experiment will be conducted at DOE's Central Receiver Test Facility, located near Albuquerque, New Mexico. The project is partially funded by DOE, and components are expected to begin arriving at the facility in the second quarter of 1983. The heat transfer fluid is molten salt, and the experiment is expected to demonstrate a number of the potential advantages of the non-phase-change fluids (molten salt and liquid metal). Three utilities (APS, SCE, and PG&E) and EPRI may contribute about 25% to the direct funding of the experiment, and a number of utilities plan to have their personnel participate in the design, assembly, and operational phases of the project (RP2302).

The EPRI-funded Brayton-cycle full-system experiment (*EPRI Journal,* December 1981) has not been continued beyond the design phase, which was completed earlier this year (RP1509). This advanced hardware development experiment was to demonstrate a complete solar-thermal, air-cooled central receiver system at the Central Receiver Test Facility beginning in 1983; the work to date will be documented and the information published in the near future. In recognition of the shift in federal program emphasis toward longer-range, high-risk research, EPRI resources were redirected toward expanding the dissemination of information on existing field experiments and supporting nearer-term development and testing efforts with industry involvement. The molten salt solar-electric experiment is such an activity and is of major importance to those industries attempting to bring central receiver technologies to commercial readiness.

Line focus troughs

This past summer, SCE also announced that negotiations with two organizations are under way to purchase power generated by parabolic trough solar-electric systems. The first project is a 12-MW (e) unit that will be supplied by Acurex Solar Corp. of Mountain View, California, and is scheduled to be operating in December 1983. It is expected that there will be 5300 parabolic trough collectors in this project, which will have approximately 700,000 m² (750,000 ft²) of collector area. The units will heat an oil to 290°C (550°F), and it is estimated that the plant will produce about 15 GWh annually.

The second project is with Luz International and involves the purchase of power produced at a 15-MW (peak) unit, which will have 111,500 m² (1.2 million ft²) of parabolic trough collectors. The collectors will raise the temperature of a heat transfer oil to approximately 205°C (400°F); it is estimated that this unit will generate 30 GW annually. The first 3-MW (e) module is scheduled to be in operation in December 1983.

Both of these units will be located near the 10-MW (e) central receiver pilot plant, and it is anticipated that some side-by-side performance comparison will be made. Financing of both these projects is being attempted through a third-party venture approach.

Two more line focus industrial process heat projects have recently been put on-line, bringing to 16 the total number of parabolic trough demonstrations funded by the federal solar-thermal program. Discussions are now under way for EPRI to assist in broadly disseminating the performance information and operating results of two of these systems to the electric utility industry. The first is a hot water supply system associated with the Caterpillar Tractor Co.'s manufacturing plant in northern California; the second is a steam supply system for a U.S. Steel Corp. plant in Ohio. At both sites, information on the impact of the solar system on the electric utility providing service will be sought (RP2003).

Point focus dishes

In April 1982 DOE's Shenandoah Solar Total Energy Project started its acceptance and test program. This unique installation south of Atlanta, Georgia, uses 114 parabolic dish collectors, each about 7 m (23 ft) in diameter, to raise the temperature of a heat transfer oil to 400°C (750°F). The system is designed to supply 400 kW of electric power, process steam at 177°C (350°F), and chilled water at 7°C (45°F) for air conditioning to a commercial knitwear factory located next to the solar project. Georgia Power Co. is operating the project, and Sandia (Albuquerque) is providing technical support during the test and operating program. EPRI will be assisting Georgia Power's efforts and will be examining the test program results for the impact on the electric utility (RP2003). Again, EPRI will support the wide distribution of the documented test results and experience obtained from this project.

This past summer DOE announced an award for the installation of a single parabolic dish power generation module to the team of Advanco, SCE, and a number of other industrial participants. The unit, a prototype commercial system, will use a 25-kW (e) engine produced by United Stirling Inc. of Sweden. The collector will be approximately 11 m (36 ft) in diameter; the module will be installed at a site near Palm Springs, California. A utility advisory group has been formed by SCE, and EPRI staff are supporting this activity. In addition, it is expected that EPRI will directly support the comparison of the performance of this module with experimental units that have been previously tested by Jet Propulsion Laboratory personnel (RP2196).

In May 1982 DOE announced that the site of the planned small-community solar-thermal power experiment will be at Osage City, Kansas. If this experiment proceeds, it will involve a number of power generation dish modules located at the same site and will be connected to the municipally owned system; the experiment is scheduled to be in operation by the end of 1984. *Project Manager: John Bigger*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager Director

PARTICULATE EMISSION CONTROL

The utility industry is rapidly accepting the use of fabric filter baghouses for controlling particulate emissions from coal-fired power plants. Within the past decade utility commitments to baghouses have grown extensively from none to 20,000-MW equivalent capacity. The majority of these units are installed on plants fueled by low-sulfur western subbituminous coal and range in size up to 800 MW. Now utility interest in high-sulfur coal applications is growing as well. In conjunction with this growth in utility baghouses, EPRI has supported a major research program to optimize the design, operation, and reliability of baghouse technology. Initiated in 1974, this program has produced results that dispel much of the misinformation associated with baghouse technology and provides utilities with quantitative data for use in engineering specifications and operation of baghouses. The most recent results suggest that baghouse size and cost can be significantly reduced without adversely affecting performance.

The EPRI fabric filter research program includes empirical analyses of two 10-MW pilot-scale baghouses (one each for high- and low-sulfur coal), collection of verification data from several full-scale baghouses, subscale experimental flow model studies, and detailed laboratory investigations. The purpose of the program is to develop sufficient understanding of baghouse performance to permit electric utilities to predict performance more accurately before construction and to develop improved designs and operating procedures.

The scope of the program to date has included the following.

- Determination of baghouse designs that achieve uniform flue gas flow distribution and minimal ductwork pressure losses (CS-2427)
- Parametric investigations of reverse-gas, shake/deflate, and acoustic bag-cleaning methods
- Bag dustcake studies
- Fabric studies
- Assessment of baghouses in high-sulfur applications

Subjects of primary interest include minimizing pressure drop (Δp) and maximizing air-to-cloth (a/c) ratios and bag life.

The majority of the pilot plant research has been conducted under RP1129 on the 10-MW fabric filter pilot plant (FFPP) at EPRI's Emissions Control and Test Facility, located at Public Service Co. of Colorado's Arapahoe station. Work has more recently been initiated on a 10-MW high-sulfur coal pilot plant at Gulf Power Co.'s Scholz station in cooperation with Southern Company Services, Inc.

The results reported here have been recently obtained from the Arapahoe FFPP. Since most utility baghouses are cleaned by the reverse-gas method, this mode of operation was studied first, although preliminary studies performed with shake/deflate and acoustic cleaning methods indicate that significant improvements over reverse-gas cleaning alone are possible.

In addition to the quantitative results reported here, there are some general results of interest. It has been determined that several weeks are required for the system Δp to stabilize after a significant change in operating conditions. Thus the test periods required are rather long for each parameter evaluated. In fact, it is not clear if the system ever truly stabilizes, particularly for reverse-gas cleaning. Because the particulate collection efficiency is inherently very high (>99.9%), the primary thrust of the program is to reduce Δp and increase the a/c ratio.

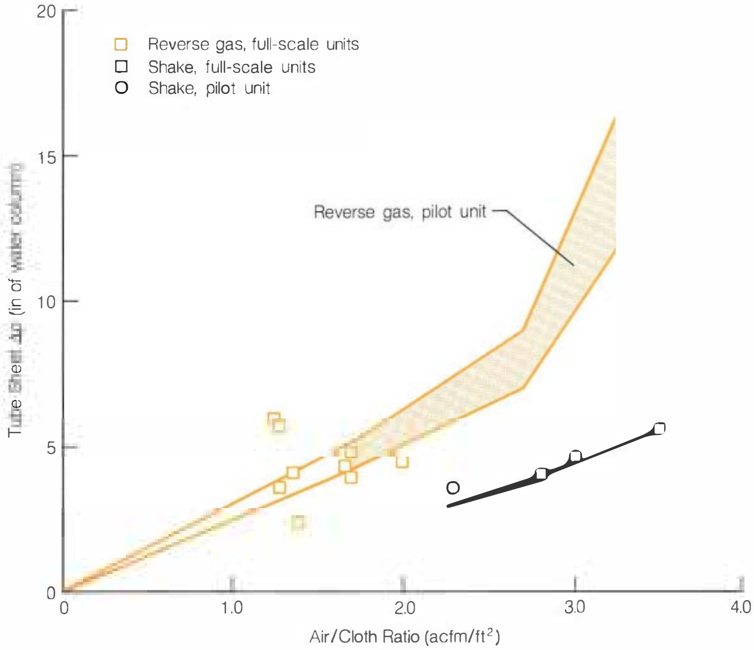
Baghouse operating characteristics

To achieve the best trade-off among baghouse capital, maintenance, and operating costs, the units should be operated at the highest practical filtration velocity, or air/cloth (a/c) ratio. The a/c ratio is, in turn, limited by Δp across the system. In the tests reported here, studies were performed to investigate the interrelationship of Δp, a/c ratio, and the dustcake on the surface of the bags in baghouses cleaned by the reverse-gas method.

The dependence of Δp on the a/c ratio determined for the FFPP is shown in Figure 1. Additional data collected for several full-scale baghouses are shown for comparison. The majority of the data are for reverse-gas cleaning, although limited shake/deflate results are also shown. All of the boilers were burning western low-sulfur coal. For reverse-gas cleaning, the FFPP curves of Δp versus the a/c ratio appear to be almost linear up to values of a/c near 3 acfm/ft² [0.015 (m³/s)/m²]. At higher values of a/c, however, the slope of Δp versus a/c is much steeper. The similarity of the data from the pilot-scale unit and the full-scale units may indicate less sensitivity to type of operation, fuel, and choice of fabrics than is commonly believed. Also, the dependence of Δp on the a/c ratio is a weaker function than anticipated, particularly below 3 acfm/ft², indicating the possibility of substantial savings in capital costs for operating at higher a/c values than the traditional value of 2 acfm/ft² [0.010 (m³/s)/m²]. Although the shake/deflate cleaning data are limited, the results shown in the figure suggest that significant reductions in Δp below reverse-gas cleaning are possible.

As part of the FFPP test series the effects of varying the amount of dust accumulated on the bags before cleaning (dust loading per cycle) were investigated for a range of a/c ratios. This was accomplished by adjusting the filtering (dwell) time between bag-cleaning cycles. The dependence of baghouse Δp on the dust loading per cycle, or conversely, time between compartment cleaning, was found to be rather weak. In plotting Δp versus dust loading per cycle with the a/c ratio as a secondary parameter, the curves were found to be linear. For example, for a/c values greater than approximately 2.3 acfm/ft² [0.012 (m³/s)/m²], Δp was found to increase with dust loading (time).

Figure 1 In the two bag-cleaning methods, shake/deflate and reverse gas, minimizing pressure drop and maximizing a/c ratios are of primary interest. Shown here is the Δp versus a/c ratio for EPRI's 10-MW FFPP and several full-scale baghouses.



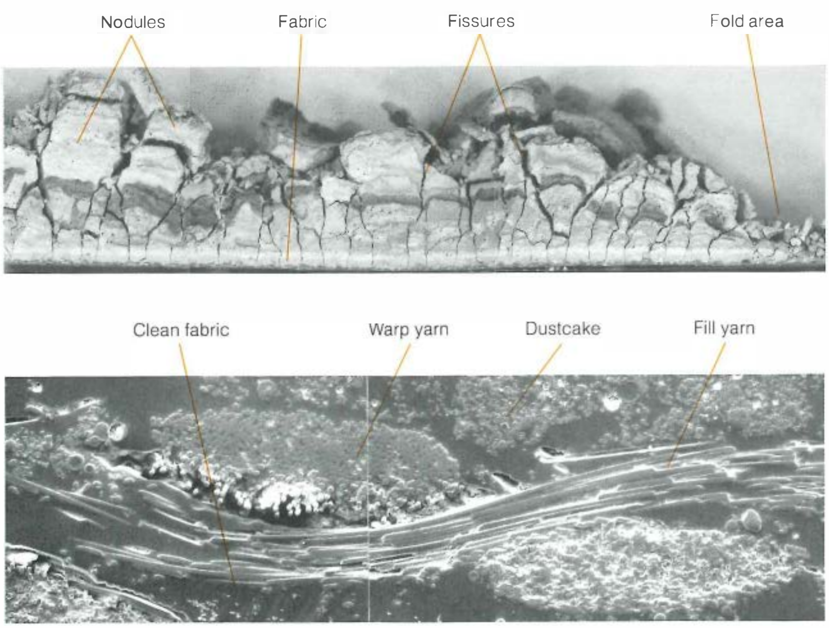


Figure 2 Cross section of glass fiber bag and dustcake (top, 89-mm segment) from a baghouse cleaned by reverse gas; micrograph of cross section at the dustcake-fabric interface (bottom, 1.2-mm segment).

On the other hand, for an a/c ratio of less than 2.3 acfm/ft², baghouse Δp was found to actually decrease with dust loading. These results indicate that the time between bag-cleaning cycles can be increased significantly beyond conventional practice without much additional Δp, and for some operating conditions, a reduction in Δp may be achieved by extending the filtering cycle. Presumably, the extended filtering times would also result in increased bag life.

Although reverse-gas cleaning is the most common method of cleaning baghouses, little information is available to quantify the relationship between the volume flow rate of the reverse gas and bag-cleaning effectiveness. However, the documented performance of reverse-gas-cleaned baghouses (Figure 1) indicates that the values of operating Δp are higher than desired. A series of tests were conducted at the Arapahoe FFPP to investigate the effectiveness of different levels of reverse gas. Three values were chosen: 6, 4, and 2 acfm/ft² [0.03, 0.02, and 0.01 (m³/s)/m²] reverse flow. The results of these tests indicate that only a small reduction in Δp, approximately 15%, can be achieved by increasing the reverse gas from 2 (current practice) to 6 acfm/ft². This is a marginal gain for such an extreme change in the reverse gas and is therefore not recommended for improving this method of bag cleaning.

Dustcake analysis

To characterize the bag dustcakes, samples were cut from the bags at each test site. Some of the samples were impregnated with a low-viscosity epoxy so that they could be sectioned and their internal structure studied. Figure 2 (top) shows the cross section of a typical dustcake from a bag cleaned by reverse gas. The cake is rugged, with large nodular deposits, deep fissures, and a thinner deposit along the fold line where the bag flexed during reverse-gas cleaning. The weight of dust per unit area ranged from 0.4 to 0.6 lb/ft² (2.0 to 2.9 kg/m²), 40–60 lb/bag, for all of the installations investigated. This cake is the residual left after cleaning, and the calculated accumulation of dust during one hour of filtering is approximately 0.05 lb/ft² (0.24 kg/m²). It therefore appears that only about 10% of the dustcake is removed by each reverse-gas cleaning cycle—probably only the freshest part of the cake. Clearly, a better means of cleaning the bags is desirable.

Figure 2 (bottom) is a higher-magnification photograph of the dustcake, showing the fabric-dust interface. Fiber bundles parallel and perpendicular to the plane of the photograph and individual particles in the dustcake can be seen. In the sample shown, the demarcation between the fabric and cake is clear, with no indication of penetration or seepage by the dust into the fabric. Some samples obtained at other installations, however, do show a much closer attachment of the dustcake, with penetration of the particles into the fabric pores.

The photographs in Figure 2 illustrate a technique that is being developed in an effort to understand the fundamental properties of the fabric-dust interactions that determine the cake structure, the path that the gas must follow, and, ultimately, the operating Δp. It is believed that the gas does not flow evenly through the cake but channels through the areas of relatively low resistance, such as the fissures and fold lines shown in Figure 2 (top). If that conceptual model is valid, methods of more thoroughly cleaning the bags would offer more effective areas for filtration and a significantly lower Δp.

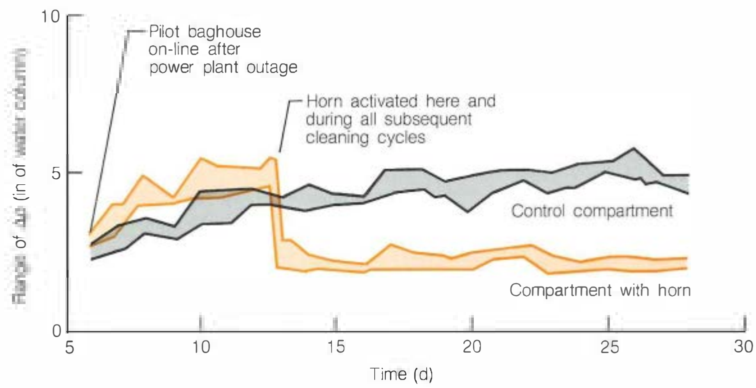
Parameters of interest in the dustcake studies are the particle size distribution, composition, electric charge, and conductivity; the fabric weave, texture, and surface treatment; and the operating parameters of the boiler and baghouse.

Studies were made of the bag swatches to determine how the permeability of the dustcake, or the drag (Δp versus a/c ratio), depended on the dustcake's physical properties. The swatches were placed in a large filter holder and their Δp-versus-a/c characteristics measured. Dust was then removed from the swatches for further analysis. The distribution of particle sizes in the range of 4–80 μm was measured with a Coulter counter and the results related to the measured drag.

The data show that there is little correlation between the drag and the weights of the cakes, the position along the bags, and the median diameters of the particles composing the cakes. The Coulter analysis indicates that the particles near the top of the bags, however, were somewhat smaller than those from the middle and bottom. These data suggest that the drag is not determined by the thickness of the cake or particle size but by the macroscopic structure (i.e., the cracks, voids, and fold lines).

Measurements of the ash chemistry, structure, and resistivity are being made for a better understanding of the factors that determine the drag, or Δp. Although the measured concentrations are small, the chemical analyses do show progressively higher concentrations of sulfate in the ash hopper samples, the smooth-cake bag samples, and the modular-cake bag samples, respectively. It has been suggested by some researchers that sulfate formation on the bag surface is responsible for the difficulty in removing dustcakes in reverse-gas baghouses. No cementitious structure has been found, however, in the microscopic analysis. Thus there is no indication that the relatively higher sulfur concentration plays a significant role in the formation or tenacity of the dustcake nodules.

Figure 3 Time history of Δp illustrating the effectiveness of sonic bag cleaning in the Arapahoe FFPP. Both compartments were operated at an a/c ratio of 2.1 acfm/ft² [0.011 (m³/s)/m²] and cleaned every three hours by reverse gas or reverse gas enhanced with sonic energy.



Recent developments

The next testing phase at the Arapahoe pilot plant will be concerned with alternative methods of cleaning bags—sonic and shaker cleaning. The sonic cleaning is particularly attractive because it offers the possibility of very effective cleaning for little additional cost, and horns can be installed on existing reverse-gas units. Shaker cleaning is also more effective than reverse gas, but there is some concern about how this method affects cost and bag life.

Results from some preliminary tests of the sonic-cleaning concept are shown in Figure 3, where Δp is plotted versus time for two compartments. One compartment is the control and is cleaned by reverse gas only. The other compartment is cleaned by reverse gas with a single horn turned on for 10 s during each application of the gas.

As illustrated in the graph, there was an immediate and dramatic decrease in Δp when the horn was used. The decrease persisted throughout the entire test period. The compartment for which data are shown was cleaned sonically during every reverse-gas cycle (every three hours). Another compartment was cleaned by applying the horn in the same way but only once a week. Although there was some decrease in Δp for that test, the effect was much less than for horn use every cleaning cycle.

As indicated in Figure 3, sonic cleaning can have a large effect on the operating Δp at a reverse-gas baghouse, but several points must be investigated: What amount of energy is required? What is the most effective frequency? Where should the horns be located? What cleaning cycle is best? What is the mechanism by which the dustcake separates from the fabric? How does it depend on the properties of the ash and fabric? How is the particle collection efficiency affected? Does the effectiveness of sonic cleaning degrade with time? Is bag life affected? These questions must be addressed before efficient systems can be designed or a large commitment to sonic cleaning made.

In summary, tests have shown that baghouses cleaned by the reverse-gas method exhibit higher Δp than necessary because of very heavy dustcakes on the bags. The gas is forced to follow tortuous paths through the cakes with the result that the resistance to flow is much higher than it would be with less dust and more uniform flow.

Alternative cleaning methods offer the possibility of significantly improved dust removal and ultimately higher a/c ratios. Little is known, however, about the dependence of the dustcake structure on the properties of the fabric, ash, or cleaning method. New techniques are being developed and studies performed to assess potential advantages and disadvantages of each method and its suitability for application in different plant situations. *Program Manager: Robert Carr*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Transmission lines parallel to railroads

One of the many difficult problems utilities face today is choosing a transmission line route that is acceptable to all concerned. The route finally selected usually involves many compromises and often is neither the utility's first choice nor the lowest-cost option. One compromise that is receiving much attention is the utility corridor concept whereby a single route is shared by many users.

A typical example of this is the routing of a new line parallel to an existing railroad right-of-way (Figure 1). Although this may not be the shortest path, the most readily accessible, or the lowest-cost option, it may be the best overall route. In some cases, it is the only route the utility will be permitted to take. When the selected route does parallel a railroad, the technical people from both the electric utility and the railroad face a host of engineering problems. The utility naturally must keep the cost of correcting excessive electrical interference on railroad signal and communication circuits at a minimum, whereas the railroad must be assured of continued safe operation of the trains.

Utility engineers faced with this situation have found that little useful information was available, and they were also dissatisfied with some of the solutions used in the past. They suggested research in this area, and in early 1982 a project was awarded to the IIT Research Institute to find better ways to solve problems associated with parallel operation of power lines and railroads.

Even before the project was started, an early goal was to involve the railroad industry as much as possible, so its advice and suggestions have been included. The railroads' concurrence and acceptance of the results are mandatory. The combined efforts of the utilities and railroads have kept this work on a realistic course, and the analytic methods and mitigation techniques developed should be acceptable to both.

Major work to date includes the following.

- A computer program has been written that will analyze the induction effects of a nearby transmission line on railroad tracks, signal circuits, and communication facilities.
- Tests have been performed on railroad signal equipment to determine the level at which interference from a transmission line could result in a problem.
- Several lower-cost mitigation techniques have been identified and further developed. Their effectiveness has been demonstrated in field tests at the Railroad Test Center in Pueblo, Colorado.

The most significant development to come from this project thus far has been that older, high-cost solutions may not have represented the best interests of either the utility or the railroad. Now, using newly developed mitigation methods, the railroad can benefit from a more versatile system with a lower

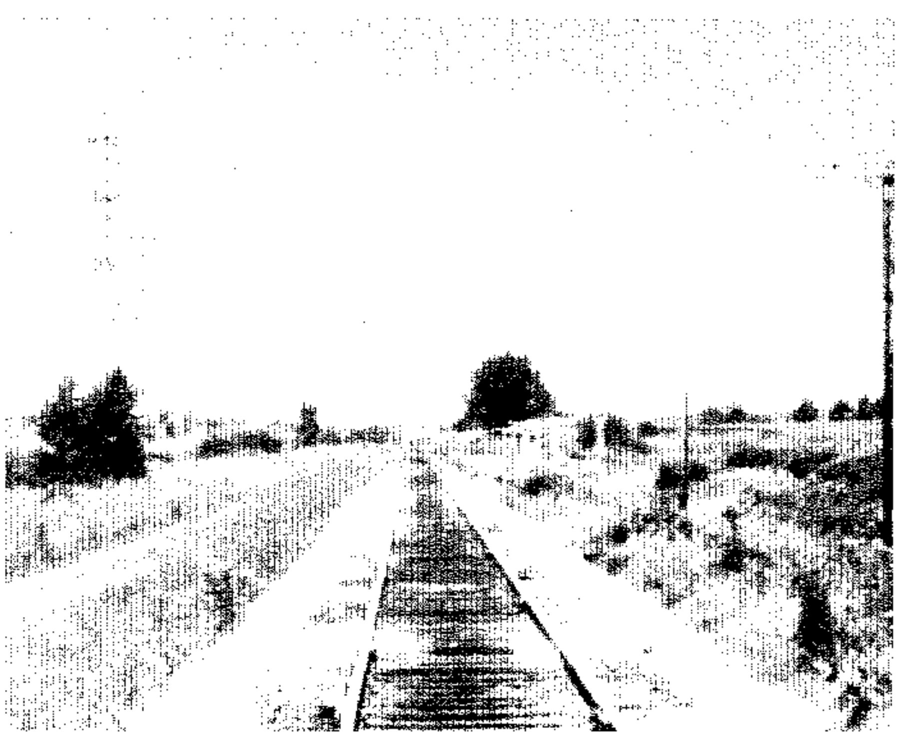


Figure 1 Research on transmission line–railroad interference problems has developed ways to share rights-of-way, keep mitigation costs to a minimum, and provide adequate (often improved) operation of the railroad's signal and communication equipment.

maintenance cost, and the utility may realize a substantial decrease in mitigation costs.

In fact, the results of this project are being used by a utility on a 500-kV line to be built along a railroad right-of-way. Although it is too early to tell, it is reasonable to believe that for this first-case situation the utility will save more in mitigation costs than the total cost of this project. And the railroad will also benefit because it will enjoy an improved signal system. *Project Manager: John Dunlap*

UNDERGROUND TRANSMISSION

Three-conductor gas cable field demonstration

Twelve months of a 24-month testing and operating demonstration have been completed on a 345-kV, three-conductor SF_6-insulated transmission system (RP7840). This prototype system, buried in a test loop at The Detroit Edison Co.'s Wayne station, is 183 m (600 ft) long (Figure 2). During 9 of the last 12 months it has been connected directly to a 345-kV overhead transmission line and has carried daily load current. Loadings were modest under this operating mode (400-A average, with an 811-A peak); the test loop commenced three-month periods in mid-1982 during which current transformers were used to induce higher currents.

The prototype system has just completed its first three-month test period of induced current in which daily cyclic loads were simulated, reaching a daily peak of 1000 A; during the next three months this mode will be repeated with a 1500-A peak, followed by another three months at a 2000-A peak. A final three-month test will be conducted during which the cable will carry 2000 A continuously. These tests will be followed by rigorous switching surge tests that will exercise the cable system to its fullest capabilities. The cable has already successfully withstood switching operations under load, including one tripout, during a period when the overhead transmission line insulators were severely iced. *Project Manager: John Shimshock*

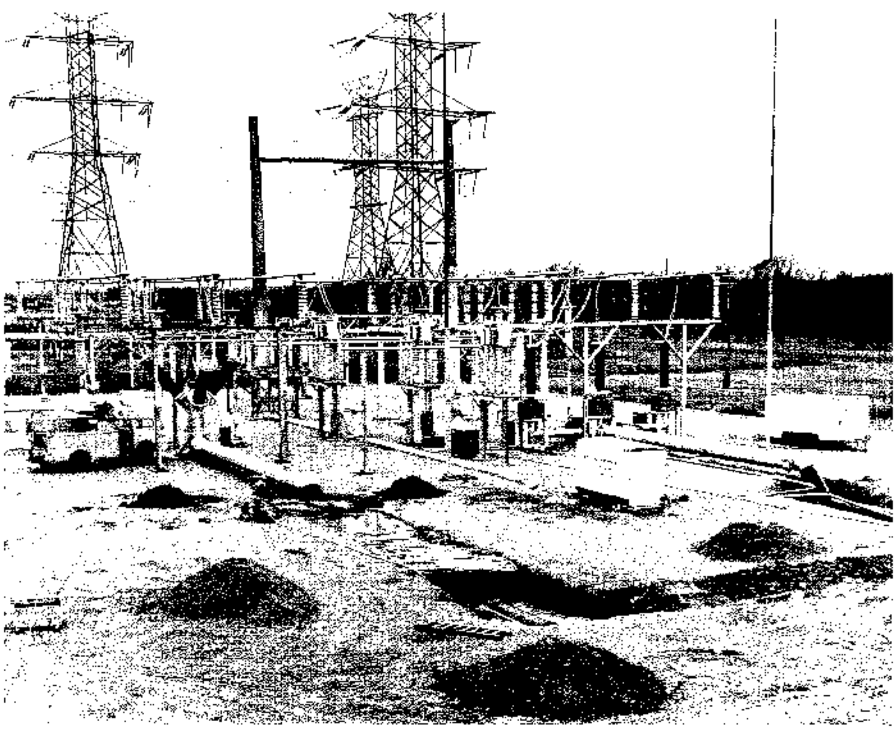


Figure 2 A portion of the buried, 345-kV, three-conductor SF_6-insulated underground transmission prototype just before backfilling was completed during 1981. The 600-ft (183-m) loop is undergoing a two-year test at The Detroit Edison Co.'s Wayne station.

Electrohydrodynamic pumping

Under a project with the University of Illinois at Urbana, EPRI has been investigating a novel method for improving pumping efficiency of oils for forced cooling of high-pressure, oil-filled underground transmission cables (RP-7871). The concept is based on the fact that an electric field in oil will attract bulk charges, which drag the oil as they move. The source of the charge is the leakage current resulting from the small power factor of the oil. Induction charging occurs when the electrical properties of the oil vary because of the thermal gradients resulting from dielectric heating of the cable.

In essence, if a layer of oil is hot near the pumping electrode and cool near the ground electrode, a uniform leakage current occurs through the oil. Because conductivity is greater in hot oil, the electric field will be smaller in that region. The variation of the electric field within the oil results in a net charge that moves with the oil in the pumping field.

In a prior report (*EPRI Journal,* November 1979, p. 53), it was noted that feasibility of the concept was demonstrated; but flow velocities of only 4 cm/s were obtained by employing a segmented electrode from a single-phase power supply that used resistors to generate three phases. Theoretically, speeds of 100 cm/s are attainable, but about 30–50 cm/s would be considered practical for this application. Recent results have indicated that pumping speeds of about 10 cm/s were reached. This speed was attained by increasing the oil power factor slightly by doping the oil, varying the experimental parameters (e.g., field strength, frequency), and employing a three-phase power supply. The increased speed is a result of a balance between electrostatic forces that induce pumping and the viscous drag of the liquid. Initially in these experiments, many traveling waves were produced at higher speeds until the parameters were refined. However, speeds greater than 10 cm/s have not been reached.

A significant observation is that a derived theoretical plot of velocity versus frequency for the fundamental operation of induction pumps indicates that a region exists for two possible values of speed. Experimental results indicate that for reasons that are not known at this time, the pump seems to select the lower velocity.

Some effort has also been made in the direction of developing a single-phase power source employing a semiconducting insulation; however, none of the commercially available materials maintained their properties with time in the oil environment.

The project is now complete, and the final report will be available in late 1982. It is clear from this work that the relatively high pumping rate required for cable applications is not likely to be attained; however, electrohydrodynamic pumping may be suitable for other applications. *Project Manager: Bruce Bernstein*

TRANSMISSION SUBSTATIONS

Subsynchronous resonance damping

Series compensation of medium and long ac transmission lines has been recognized as a powerful tool for optimizing the economical use of transmission lines, improving system stability, and increasing power flow through intended routes. This technique is extensively used in the western United States and in many other countries. However, the technical problems of maintaining the reliability of capacitor protective equipment and preventing the amplification of subsynchronous resonance oscillation (below 60 Hz) of large steam turbogenerator shafts have been a deterrent to widespread and effective use of series compensation.

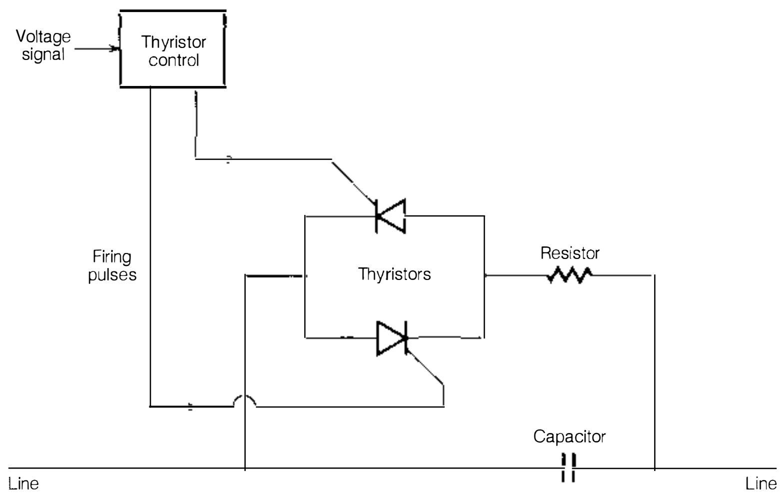
A new solution has been developed, referred to as the NGH subsynchronous resonance scheme, which is intended to reduce transient machine oscillations during system disturbances, suppress steady-state subsynchronous resonance, suppress dc offset of the series capacitors, and protect the series capacitors.

The basic electrical configuration for one phase is shown in Figure 3. It involves a linear resistor in series with back-to-back thyristors connected across the capacitor. When a zero voltage crossing point of the capacitor voltage is detected, the succeeding half-cycle period is timed. If and when the half-cycle exceeds the set time (8.33 ms for 60-Hz half-cycle), the corresponding thyristor is fired to discharge the capacitor through the resistor and bring about its current zero sooner than it otherwise would. The thyristor stops conducting when the capacitor voltage, and therefore the thyristor current, reaches zero. Thereafter, the measurement of the half-cycle period restarts from a new voltage zero. Two thyristor switches are needed for the two polarities, and for high voltages the thyristor switches are made up of a series of low-voltage thyristors. If there is no subsynchronous current flowing through the capacitor, the capacitor voltage is a symmetrical 60-Hz waveform, and the NGH circuit remains inactive. However, when subsynchronous frequency (less than 60 Hz) current flow mixes with 60-Hz current, the NGH circuit removes and dissipates the excess energy from the capacitor and prevents participation of the transmission line in the subsynchronous oscillations.

In addition, protection of the series capacitor is provided by firing the corresponding thyristor switch if instantaneous voltage exceeds the safe capacitor voltage.

Extensive studies on Southern California Edison Co.'s Mojave generation-transmission and Salt River Project's Coronado generation-transmission showed this scheme can effectively solve subsynchronous resonance problems for both schemes (RP1504).

Figure 3 Basic NGH subsynchronous resonance damping scheme.



The gravity of the subsynchronous resonance problem was recognized when the Mojave units were damaged twice, once in 1970 and again in 1971 (Figure 4). Since then, four Arizona-to-California transmission lines have been operating at a reduced series compensation of 16% even though 70% compensation has been installed. This has resulted in reduced transmission capacity and higher transmission losses.

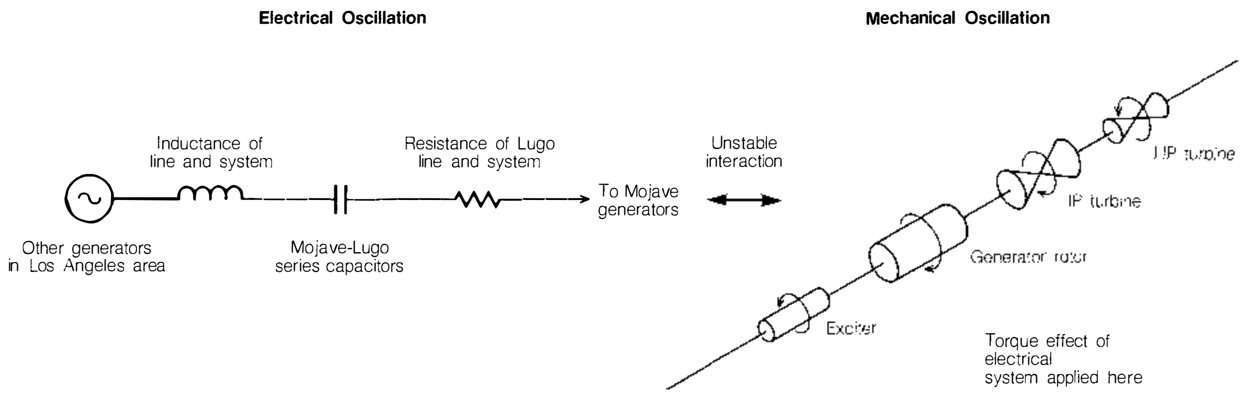
Extensive simulation study at the Siemens-Allis Hybrid Computer Facility in Atlanta for the Mojave system showed that application of the NGH scheme on four out of eight series capacitor modules on the four lines will completely solve the problem and allow full use of available transmission capacity (Figure 5). Specifically, the study on the Mojave system showed that the scheme accomplished the following.

- Removed subsynchronous current components
- Reduced peak electrical torque
- Damped transients within two cycles
- Drastically reduced shaft torques due to system faults and switching
- Protected series capacitors and removed dc offset across series capacitors during reinsertion

On the basis of these encouraging results, it was decided to demonstrate the NGH scheme for one series capacitor module. With significant financial contributions by EPRI and Southern California Edison and small financial contributions by Arizona Public Service Co., Los Angeles Department of Water & Power, Nevada Power Co., Salt River Project, San Diego Gas and Electric, Tucson Electric Power Co., and Western Area Power Administration, a contract has been awarded to Siemens-Allis Corp. to design, manufacture, and deliver one prototype scheme by the end of 1983. The prototype will be installed and tested by Southern California Edison at the Lugo substation across one segment in each phase of the series capacitor in the Eldorado-Lugo 500-kV line.

The prototype will consist of a 60-kV, back-to-back thyristor switch in series with a 2.65-Ω resistor with an inductance of 500 μH. The 60-kV thyristor switch will be made of 18 thyristors in series for each polarity, a total of 36 thyristors. Control equipment will be located at the ground level for easy access and monitoring; it will be connected to the main equipment on the 500-kV platform by optical fibers. *Program Manager: Narain G. Hingorani*

Figure 4 Subsynchronous resonance integration for Southern California Edison's Mojave turbine generators, showing how the interaction occurs between the electrical system and the mechanical system.



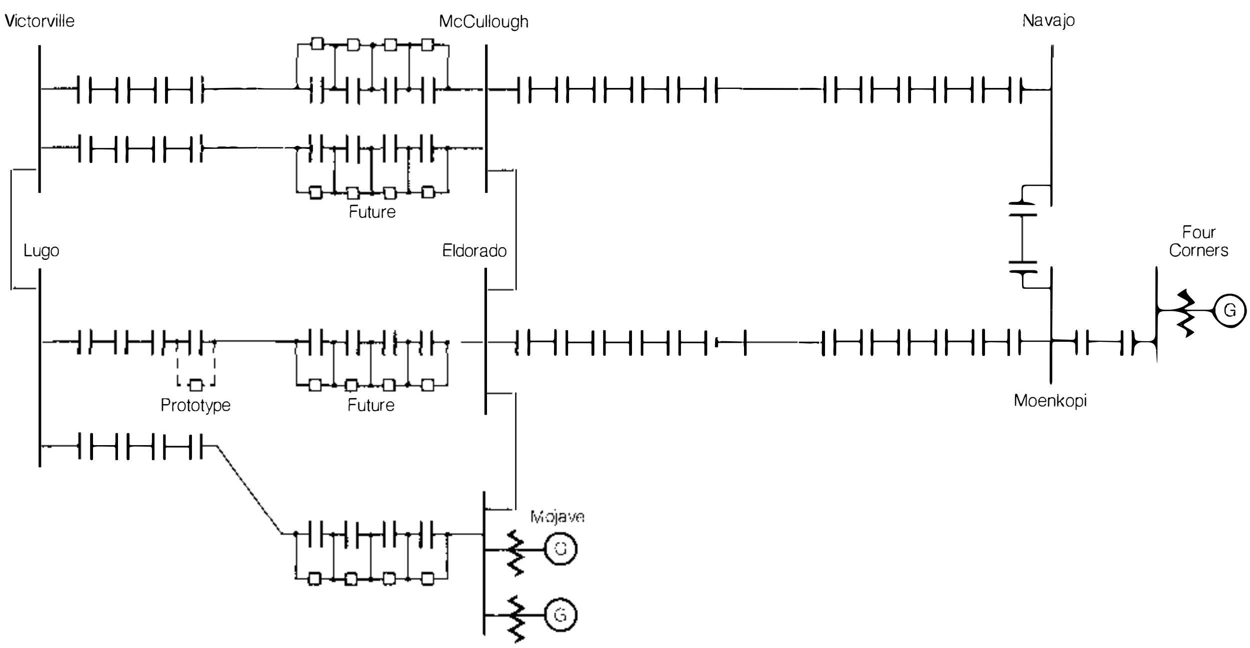


Figure 5 NGH subsynchronous resonance damping scheme installation for Mojave SSR protection, showing the location of the prototype scheme to be demonstrated and the location of the future installations required to solve the SSR problem for the Mojave plant.

Measurement of PCBs in transformer oil

Recently concluded is the field evaluation of an instrument made by Horiba that can be used as a screening device. By a five-minute automated test routine on this instrument, an oil sample can be tested for its chlorine content, and all oil samples that have low chlorine readings (approximately one-half to two-thirds) can be eliminated. Because the relationship between chlorine detected and polychlorinated biphenyl (PCB) content varies for different PCB isomers, samples with higher chlorine readings must be retested to determine the precise level of PCB contamination (*EPRI Journal*, July/August 1982, pp. 42–43).

Since December 1981 Battelle, Columbus Laboratories has been working to develop an instrument that uses infrared light to measure PCB contamination in transformer oil (RP2131). The infrared light passes through oil samples taken from the transformers, and the PCB molecules absorb the light to form a pattern on the instrument recorder. By analysis of this pattern a quantitative measure of the PCB content can be obtained. It is estimated that through this fully automated test procedure, each of the oil samples can be tested in about five minutes.

The instrument will be designed to have a fully automated test routine, permitting utility operations personnel to carry out the necessary tests either in the laboratory or out in the field. The instrument should be portable enough to be transported and operated in the back of a station wagon.

While this development is under way at Battelle, a manufacturer will be enlisted to commercialize the device by the end of 1983. *Project Manager: Vasu Tahiliani*

Microprocessor-based converter control system

High-voltage dc (HVDC) converters have been the proving ground for many innovations that eventually benefited both dc and ac systems. The nature of the technology requires a high-speed control system for proper operation. Advanced control equipment has therefore been a part of converter stations from the start. Vacuum tube amplifiers were retired in favor of transistors in the early 1960s; integrated circuits began to be used in the mid-1960s; and digital computers for control of the HVDC system were introduced in the late 1960s, which was four or five years before the computer in general was entrusted with similar tasks in ac substations. It is therefore not surprising that microprocessor applications have begun to be found in converter stations. However, because of the speed limitations of the microprocessor, the applications have been primarily in the slower control loops of the converters. The time now appears to be right for introduction of the microprocessor to the more demanding tasks of the valve firing control system. EPRI therefore decided to sponsor the development of a microprocessor-based converter control system through a contract with General Electric Co. (RP1942).

This project is attempting to implement the valve firing control system in a microprocessor-based system. Setpoints will be received from other controllers and converted to a set of firing pulses for a 12-pulse converter. At this time, the design of the hardware and software modules has been completed and system integration has begun. The project will end early in 1983 with a laboratory demonstration of a controller. *Program Manager: Stig L. Nilsson*

Acoustic partial discharge detector

In the *EPRI Journal*, April 1981, it was reported that a single-channel acoustic detector had been completed (RP426). Several of these detectors have been purchased by utilities from Dunegan-Endevco Co. The best use of the single-channel detector has been in conjunction with gas analysis from oil samples of suspect transformers. Many times gas analysis has indicated the possibility of a partial discharge, and the detector has been able to verify its existence.

The detector attempts to measure the acoustic energy in the discharge by digitally counting the number of pulses above a threshold value. The readings obtained cannot easily be referenced to any of the user's frequently known references (e.g., amps, volts, ohms). Consequently, quantification of these values to simulated sources of partial discharge has been part of this project. The single-channel detector by itself, however, cannot give an absolute reading that depicts the severity of the discharge.

Consequently, the second phase of this project was initiated to build a two-channel detector that could locate the discharge. The operational sequence for using the device is as follows.

- Identify from gas analysis that a partial discharge is suspected in a transformer.
- Verify the existence of the discharge with the single-channel detector.
- With the two-channel detector, place the two transducers on the outside of the tank (using a magnet and acoustic couplant) until maximum readings are found. By several techniques involving intersecting lines and planes, the exact location of the discharge can be found. (Multiple sources can also be located.)
- With the help of the transformer manufacturer, the source of the discharge can be determined. Knowing the attenuation of the discharge through the various materials in the transformer, the intensity of the discharge can now be quantified and decisions made on corrective action.

These acoustic detectors have been used in the field without experiencing any interference from electric or magnetic fields or noise sources like pumps or fans because the detectors use a band pass filter between 100 and 300 kHz. Other noises (e.g., from the core, pumps, and fans) are contained in a spectrum below 100 kHz.

This valuable new tool can be a lifesaver to all operating and engineering divisions of utilities that are faced with the problem of deciding the correct course of action when severe gassing occurs in a transformer and a partial discharge is present. *Project Manager: Edward Norton*

DISTRIBUTION

Concentric neutral cable corrosion

The corrosion of copper concentric neutral wires surrounding underground residential distribution (URD) cables is a problem of increasing concern to utilities. The potential consequences of an open neutral are well understood by the utility industry.

During 1982 EPRI completed a three-year project to determine the cathodic protection criteria and guidelines necessary for the control of corrosion in direct-buried copper concentric neutral cables (RP1049). Volumes 1 and 2 of the three-volume final report were published in 1981 (EL-1970); Volume 3 will be issued shortly under the same number.

Of particular interest in these reports are details of the electrochemical, chemical, bacteriological, and sieve analyses of soils from various test locations. Also, some causes of neutral corrosion are included, along with protection criteria. The latter are covered thoroughly in an earlier article on this project (*EPRI Journal,* June 1981, pp. 38–39).

In summary, it has been found that certain criteria can be used to determine the effectiveness of the cathodic protection. For example, a negative voltage shift of at least 100 mV, measured after cathodic protection current has been applied for several days, is a good indication that the protection system is working. A negative voltage shift of 150 mV can be expected from an effective protection system after it has been applied for several months. In either case, a negative voltage of at least 300 mV should be measured between the concentric neutral and a $Cu/CuSO_4$ reference electrode. However, this last measurement is not reliable in areas with high ac leakage currents.

Research to date indicates that the following is the proper procedure to use when installing a copper concentric neutral cathodic protection system.

▫ Check continuity of concentric neutral wires. Cathodic protection should not be applied on cables with open wires.

▫ Replace cables having corroded wires.

▫ Measure soil resistivities (5-ft and 10-ft [1.5-m and 3-m] depths) at transformers, splice, and switch boxes, or, as a general rule, every 300–1000 ft (90–300 m) along the concentric neutral cable.

▫ Use packaged Zn or Mg galvanic anodes and/or impressed current systems at transformers and secondary boxes in areas with soil resistivities of less than 1000 Ω-cm.

▫ Use Mg galvanic anodes and/or impressed current systems at transformers and secondary electric boxes in areas with soil resistivities of 1000–10,000 Ω-cm. When the soil resistivities are above 5000 Ω-cm, the impressed current system outputs will be greater and therefore more effective than the galvanic systems.

▫ If possible, select locations where the cable is accessible without costly excavation, such as transformers or splice boxes. Generally, the optimal distance between the systems is 300–1000 ft (90–300 m), and the protection current density is 100 mA/1000 ft of concentric neutral cable or less.

▫ Select the type and number of galvanic anodes. The optimal output of one system is between 100 and 250 mA.

▫ Install the systems, maintaining a 10-ft (3-m) distance between anodes, neutral wires, and other structures, whenever possible. When problems with space or right-of-way are encountered, maintain 5 ft (1.5 m) or more between the anode and the concentric neutral and other structures connected to the neutral wires. However, maintain a 10-ft (3-m) distance between the anode and other metallic structures not connected to the neutral wires to eliminate interference effects.

▫ Before connecting the systems to the concentric neutral wires, measure the following: neutral wire potential with $Cu/CuSO_4$ electrode 5 ft (1.5 m) from test stations, transformers, or boxes; neutral wire potential with $Cu/CuSO_4$ midway between the systems and above the cable; and resistance between the anodes and neutral wire.

▫ After energizing the rectifiers and/or connecting the galvanic anodes to concentric wires and, if necessary, adjusting the output with a resistor, measure the following: current and voltage of the rectifier or current output of galvanic anode or anodes for each system and repeat the above tests. Determine neutral wire potential shifts for both tests.

▫ If the neutral wire potential shift with the $Cu/CuSO_4$ electrode is less than −100 mV after several days' polarization, install another system midway between the existing cathodic protection systems.

The cost of materials for one cathodic protection system was approximately $200 in 1982. A two-person crew with a boom truck and auger can install from two to six cathodic protection systems in eight hours if no concentric neutral cable excavations are necessary.

Although the research in this project has been completed, several long-term tests are in progress, namely, corrosion evaluation of alternative concentric neutral wire materials; ac corrosion effects on neutral wires; excavation and evaluation of neutral cable samples; and excavation and evaluation of platinized anodes and dissolution rates of platinum in soils and backfills. *Project Manager: T. J. Kendrew*

Optimization of metallic cable shields

The metallic shield–concentric conductor of large extruded dielectric power cables used in three-phase feeders carries charging, circulating, and unbalanced load currents (if so connected) during steady-state conditions and carries short-circuit current during a fault. Of all these currents, short-circuit current is by far the largest and is therefore the chief determinant of neutral size. During faults, the shield must not get so hot as to extensively damage the cable, which is of particular importance in direct earth-buried installations. Up to this time, however, we have not known how hot is too hot.

Cable standards now specify a neutral shield conductor having one-third the conductance of the insulated conductor. In addition, a permissible shield temperature of 200°C (392°F) is recognized for thermoplastic shield/jacket compounds under fault conditions. Before this project started, the work of some researchers indicated that shields designed by existing standards were larger than necessary. Hence this EPRI-funded research project to optimize the design of the metallic shield–concentric conductor (RP1286).

During this project 26 different cable designs were subjected to typical fault currents and reclose sequences to determine the safe withstand transient temperature rise of the shield. The cables had various combinations of typical insulation shields, jackets, and metallic shields. Both new and aged cables were used. A number of cable designs were also tested while bent 90° on a 36-in (0.9-m) radius.

The conclusions were that many of the cable constructions could withstand safe shield temperatures much in excess of 200°C (392°F). The withstand temperature was determined by the ability of the cable to pass physical and electrical tests after the short-circuit test. It was found that many combinations could safely sustain shield temperatures of 400–600°C (752–1112°F), which makes highly feasible the use of a metallic shield–concentric conductor conductance lower than that normally employed on such cable.

Mathematical models were developed for both round wire and flat strap neutrals that checked closely with experimental results. The models were incorporated in simple computer programs that the utility engineer can use to optimize the shield size for a specific system.

A simplified laboratory model short-circuit test procedure was developed that simulates the damage (or lack of it) incurred in full-scale short-circuit tests. This model test is easy to perform and requires only a minimum of readily available equipment. Because this procedure will be especially useful in evaluating new cable materials and constructions, cable manufacturers are expected to be the primary users.

The immediate payoff of this project is that utilities can confidently specify a metallic shield with less copper than they are probably using now. This saves two ways: initial capital investment and neutral losses are decreased. To maximize the loss savings, the metallic shield should be reduced to the lowest possible conductance. This may make a change of insulation shield and/or jacket compounds desirable, and perhaps entail a slightly higher cost for these materials. But copper and losses are far more expensive than plastic, so the trade-off should be negligible. *Project Manager: Herbert Songster*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

FORECASTING TOOLS FOR SMALL ELECTRIC SYSTEMS

In 1979–1980 members of the rural electric industry assessed their long-range forecasting methods under the auspices of EPRI's Utility Modeling Forum. Individual distribution cooperatives, the Load Forecasting Committee of the Generation and Transmission Managers Association, the National Rural Electric Cooperative Association (NRECA), and the Rural Electrification Administration (REA) all participated in this project. They found that cooperatives could benefit from greater use of mathematical and statistical tools in their forecasting, but that cooperatives' size imposed resource constraints. Analytic tools could help identify the key influences on past electric use and could improve forecast documentation and explanation. The major obstacle is that many small electric systems lack the means to determine which tools are available, their costs, and how they perform in practical applications.

A project was initiated in 1981 to overcome this obstacle by studying residential consumers' kWh use. The residential class is typically large and is the most conducive to an analysis of electricity use. The project will conduct four test cases with four rural distribution cooperatives (Table 1).

Structure of the project

The three types of forecasting tools, or models, being investigated are time trend, econometric, and end use. (The end-use model is not discussed in this report.) The test for each case study has four stages: data collection, model development, forecast development, and evaluation. The variety of forecasting tools to be tried depends on the availability of data. For example, appliance saturation data are necessary for an end-use model.

Some test case utilities have not completed appliance saturation surveys. Number of man-hours, amount of computer time, and other costs of testing will be recorded.

Evaluation criteria include statistical validity, cost, comprehensibility to the forecaster, and plausibility to the decision maker. The evaluation is carried out within the context of the test case. This project's objective is not to find the best forecasting tool. Rather the goal is to demonstrate the relative benefits and costs of a variety of models in a variety of situations.

Four forms of time trend models based on annual data have been developed. Time trend models can be accurate and relatively inexpensive forecasting tools. However, by its nature, a time trend model provides no means of identifying the key underlying factors that affect the trend. It cannot help explain a forecast. In this project, time trend models serve as benchmarks for determining how much it costs to develop explanatory capability.

The project has also developed four econometric models. They use the following factors to account for the past pattern of residential

Table 1
TEST CASES

Distribution Electric Cooperative	Generation and Transmission Electric Cooperative	Peak Season	1981 Peak (MW)	1976–1981 Peak Growth Rate (%)	1981 Population Density (customers per line mile)
Choctawhatchee DeFuniak Springs, Florida	Alabama Andalusia, Alabama	summer	41	2.7	6.1
Platte Clay Platte City, Missouri	Associated Springfield, Missouri	winter	52	5.7	4.3
Southern Maryland Hughesville, Maryland	(no affiliation)	summer	262	6.4	12.0
Adams Gettysburg, Pennsylvania	Allegheny Harrisburg, Pennsylvania	winter	53	4.5	7.5

kWh use: number of residential customers, average inflation-adjusted price of electricity, heating degree days, and cooling degree days. These four models differ in their unit of observation: annual data, monthly data, monthly observations of 12-month sums, and monthly 12-month sums adjusted for the statistical problem of autocorrelation. The REA is especially interested in the different observation units. Each of the four econometric models represents the best of several functional forms judged on a statistical basis.

Figure 1 compares the time trend logarithmic model with the econometric annual model. The econometric model is better able to track past history. The high and low range of the time trend forecast appears smaller than the range of the econometric model. This comparison is one of apples and oranges, but it brings out interesting aspects of each approach. The range of the time trend is based solely on the size of errors made in explaining historical facts. The underlying hypothesis is that the revealed pattern will continue, but with random perturbations.

In forecasting with an econometric model, one must make forecasts for each of the explanatory factors. The difficulty of doing this depends on the factor. Climate is normally assumed to remain constant, so 30-year averages are used to forecast weather. However, the future inflation-adjusted electricity prices and the future number of households are uncertain quantities. The range of the econometric forecast in Figure 1 stems from different plausible forecasts made for these two factors.

Table 2 shows the results of all eight models developed. There appear to be differences between the model types and among models of the same type on all the dimensions portrayed. However, any real conclusions must wait for the evaluation stage.

Continuing research

Representatives of the Load Forecasting Committee, NRECA, and REA are continuing to review this project. They have identified several additional econometric models to be explored in this project.

The number of residential customers will be forecast independently of the kWh use per residential customer. This approach will give a more realistic measure of how accurately the historical pattern of electricity use is explained by a limited number of factors.

Electricity is only consumed in conjunction with durable goods, such as refrigerators and air conditioners. A consumer's full response to a price increase may be delayed until the appliances wear out several years later. This pattern of electricity use can be

Figure 1 A comparison of two forecasting models of residential electricity sales shows (top) the annual econometric model, whose explanatory factors are consumers, real electricity price, heating degree days, and cooling degree days; (bottom) the logarithmic time trend model.

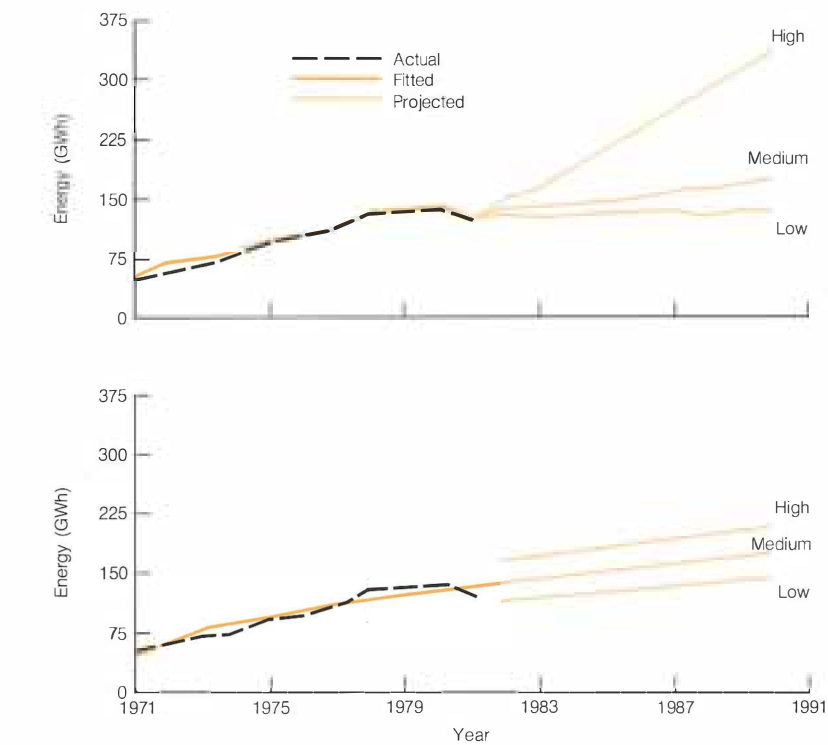


Table 2
PRELIMINARY RESULTS AND COSTS

Model	R^2	Forecast Growth Rate for Residential kWh (%) 1981–1985	1981–1990	Model Development Cost* Man-hours	Dollars
Econometric					
Annual	0.99	6.3	4.6	32	300
Monthly	0.99	5.8	4.4	48	500
12-Month Sum	0.98	9.3	7.8	48	500
12-Month Sum Autocorrelation Adjusted	1.00	8.8	7.5	64	750
Time Trend					
Linear	0.93	10.6	7.2	4	20
Logarithmic	0.95	7.0	4.6	4	20
Exponential	0.85	17.7	13.6	4	20
Curvilinear	0.97	2.5	−2.1	4	20

*These preliminary estimates assume complete model development and ignore savings from developing multiple models. They are for comparison only.

captured by using last year's kWh use as an explanatory factor.

This project's objective is to test a limited number of new forecasting tools and to communicate the results to the industry. Workshops on these residential forecasting tools are planned for early 1983. The final report will be a reference guide and is scheduled for publication in mid 1983. *Project Manager: Joseph Wharton*

SURFACE WATER ACIDIFICATION

The integrated lake-watershed acidification study (ILWAS), started in 1977, will soon be completed. The primary objective of the study has been to quantify the relationship between the deposition of atmospheric acids and the acidity of surface waters. Preliminary results indicate the importance of using an integrated ecosystem perspective to assess surface water vulnerability to acidification; the insufficiency of using bedrock geology as a sole indicator of vulnerability; and the importance of soil mineralogy, soil depth, and watershed hydrology in evaluating vulnerability. A follow-on regional integrated lake-watershed study (RILWAS) has been undertaken to increase the robustness of the general theory of surface water acidification developed in ILWAS and to develop strategies for assessing vulnerability over an entire region.

Progress in ILWAS

Precipitation follows various pathways through a terrestrial system before it reaches a lake (Figure 2). Biogeochemical processes acting in series and in parallel produce or consume acids and release chemicals that shift the pH equilibrium. Scientific investigation of a single process is not sufficient for understanding the chemical behavior of rain as it becomes lake water. The results of one process may be modified by others to yield results that may be counterintuitive and conflicting. An integrated approach is needed.

An integrated, interdisciplinary, multi-institutional study of three forested watersheds was started by EPRI in 1977 to quantify the relationship between the deposition of atmospheric acids and surface water acidity and to provide a general framework for answering scientific and management questions about acidification of surface waters (RP1109). For example, one question that could be addressed is what would happen over time to lakes in a given region if the acidity of precipitation were to be doubled or halved.

The three watersheds are located within 19 mi (30 km) of each other in the Adirondack Park region of New York. Each watershed receives about the same amount of precipitation of nearly identical quality, but each has a lake with different pH dynamics (Figure 3). Of the three lakes, Woods is considered acid (typical outlet pH between 4.5 and 5), and Panther is neutral (typical outlet pH near 7). Sagamore Lake has a much larger watershed with more spatially heterogeneous biogeochemical characteristics, but its outlet pH is typically between that of Woods and Panther. During the spring snow-

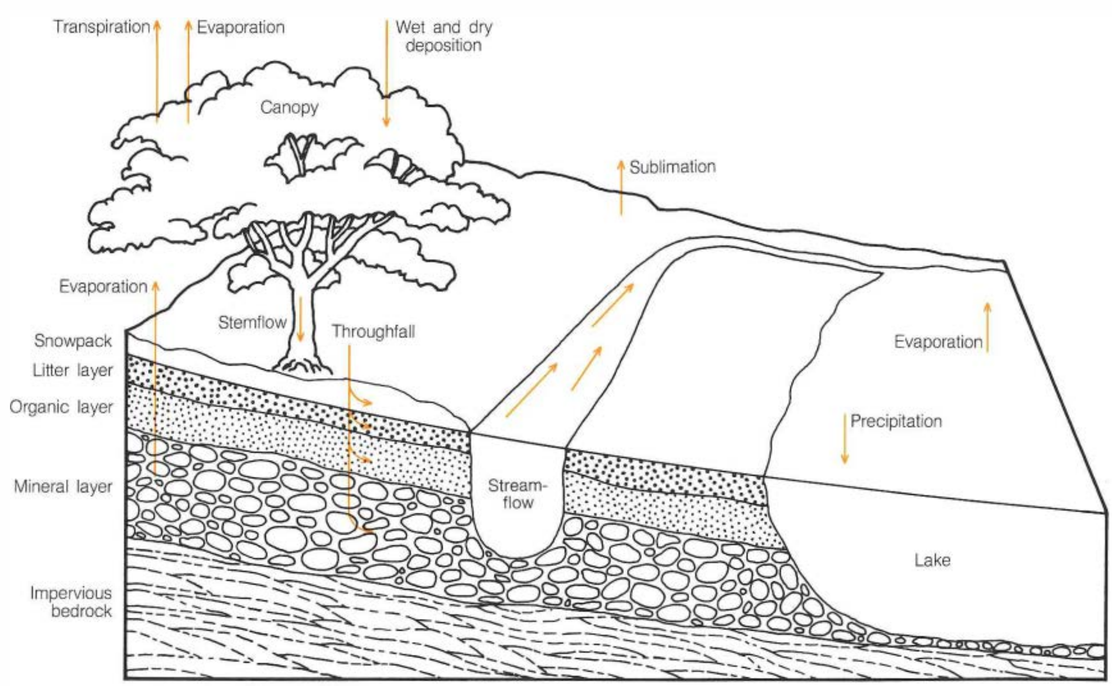
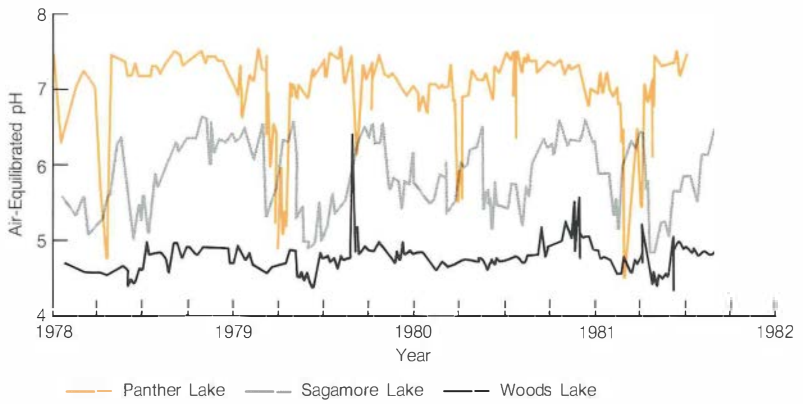


Figure 2 Flowpath of water through a forested catchment.

Figure 3 Outlet pH of Sagamore, Panther, and Woods lakes from January 1978 to July 1981.



melt Panther Lake's outlet undergoes a rapid transient increase in acidity (Figure 3). Acidification does not occur throughout the entire depth of the lake but only at the surface. Soon afterward, the surface water warms and becomes denser than the deeper water. The surface and deeper waters of the lake mix, which results in a solution of uniform neutral pH with depth and a rapid return of the entire lake to neutrality.

Based on a conceptual model, the watersheds have been divided into a cascade of compartments: atmosphere, canopy, snowpack, soil system, bogs, streams, and lake. Data are collected for each compartment to evaluate its acid-producing and -consuming processes and to calibrate and verify a mathematical simulation model, which is being developed to follow the quantity and quality of water moving through the system from treetop to lake outlet.

Data collection was completed last December, and synthesis and analysis are under way. The computer program of the model has been completed, and various tests and analyses (e.g., sensitivity analyses) are being performed. A multivolume final report is planned. Two volumes—data set and model documentation—are scheduled for publication by the end of the year. The remainder of the volumes will be completed during the first half of 1983. They include a user's manual for the model, detailed topical reports on major aspects of the study (e.g., atmospheric input, lake chemistry, surficial geology, vegetation, and soils), and an overall synthesis volume.

Analysis to date has produced two preliminary general results of major importance. The first is that vulnerability of a lake to atmospheric acidification, in general, cannot be established by studying the lake in isolation. Before ILWAS was begun, the analogy most commonly used to explain atmospheric lake acidification was the titration of a beaker of alkaline solution. The lake (solution) was assumed to have some finite alkalinity that was consumed as acid was deposited. ILWAS has shown that this analogy is, in general, inaccurate and that a lake's vulnerability to acid deposition must be evaluated in the context of the biogeochemistry of its entire catchment, including both terrestrial and aquatic components.

The second general result is that characterizing bedrock geology is not sufficient to define the vulnerability of a region's surface waters to acidification by atmospheric inputs. Before the study, it was commonly assumed that areas such as the Adirondacks, which are underlaid with granitic (nonreactive) bedrock, were highly vulnerable to atmospheric acidification because such bedrock has very little neutralizing potential. However, the study has shown that the deep mineral soil layers (shown in Figure 2) have considerable and heretofore unrecognized neutralizing capacity.

Preliminary analyses also provide insights into why the acidity of the three lakes is different. Mineral soil is the major source of neutralization in the ILWAS watersheds. Its neutralizing capacity should be a function of its depth. Greater soil depth can increase both the distance the water travels through the soil and the amount of time it remains there. That soil depth and neutralization are related is consistent with the observation that the soils of Panther Lake watershed are much deeper (average depth, 17.1 m) than those of Woods Lake (2.2 m). Figure 4 shows the results of three model simulations of Panther Lake watershed. Each simulation assumes a different average soil depth, corresponding to the watersheds of Panther, Sagamore, and Woods lakes. For each simulation, all watershed characteristics other than soil depth are Panther's. Where soil depth is decreased to values representative of the Sagamore and Woods watersheds, the simulated annual average of the lake outlet pH also decreased to values representative of those systems.

When the snow melts in Panther Lake watershed, large amounts of water flow quickly through the shallow soil layers to the lake, bypassing the deeper mineral layers. Neutralization is curtailed and acidity quickly increases in the surface water of the lake (Figure 3).

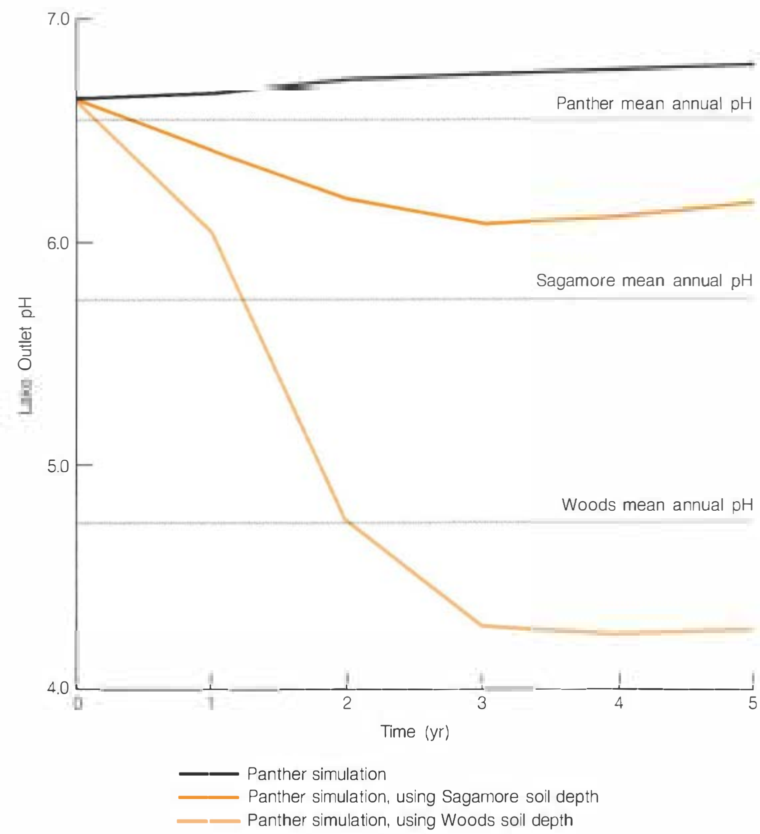
Progress in RILWAS

A follow-on study to ILWAS was started this year (RP2174). The two objectives of RILWAS are to test and increase the robustness of the ILWAS model by applying it to areas outside the Adirondacks and to develop and test a methodology to assess the vulnerability of an entire region (in contrast to a few individual lakes) to acidification by atmospheric acids.

The first objective is being addressed in both northern Wisconsin and the southern Appalachians. In northern Wisconsin, EPRI is cofunding an integrated lake-watershed study of two watersheds with a group of Wisconsin utilities, the Wisconsin Department of Natural Resources, and the U.S. Geological Survey. The lakes, hydrology, and soils of these systems differ from the Adirondack ones studied under ILWAS. The Wisconsin lakes are seepage lakes. That is, they have no surface inlets or outflows and thus are completely governed by the hydrology of local and perhaps regional groundwater systems. The Wisconsin soils were formed from sandy glacial outwash and are several hundred feet thick. The Adirondack soils, on the other hand, were formed from glacial till and are several feet to tens of feet thick.

In cooperation with TVA and the U.S. Forest Service, EPRI is also applying the model developed in ILWAS to a watershed in the southern Appalachians. Southern Appalachian watersheds have a number of unique hydrologic, soil, and climatic features. The principal surface waters of interest in this

Figure 4 Simulated annual average outlet pH for Panther Lake, assuming three watershed soil depths. One depth is Panther Lake's actual soil depth; the second simulation is Panther Lake, assuming the soil depth of Sagamore Lake; the third is Panther Lake, assuming the soil depth of Woods Lake.



region are headwater streams and large reservoirs. These differ from the small ponds in the Adirondacks and in Wisconsin. Because the southern Appalachian region has never been glaciated, its soils, which are millions of years old, are much older than Wisconsin or Adirondack soils, which are about 10,000 years old. The absence of snowpack in the south should permit better resolution of the watershed sources of nitric acid production than is possible in the north.

Policymakers and the general public are not so much concerned with the fate of individual lakes as they are with the fate of an entire lake region. The second RILWAS objective is to develop a regional assessment methodology that has greater validity than regional one-time surveys of surface water chemistry, but this is not as complex, time-consuming, and costly as applying the very intensive ILWAS approach to every lake in a region. This part of the study is being carried out in the Adirondack Park area, where 20 study watersheds have been selected to represent the variety of environmental situations that exist in the region. Watersheds have been selected to include a variety of mineralogies, bedrock types, hydrologies, and fisheries.

In addition to its two objectives, RILWAS will also attempt to relate lake fisheries to watershed characteristics and biogeochemistries. The Adirondack Park portion of RILWAS is cofunded by New York utilities and the U.S. Geological Survey. RILWAS is scheduled to be completed by the end of 1985. *Project Manager: Robert Goldstein*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

RECYCLING OF SPENT NUCLEAR FUEL

Although commercial reprocessing activities were halted in the United States in the late 1970s, nuclear fuel reprocessing has continued to be the basis for national energy planning in France, West Germany, Great Britain, Japan, and other countries. As a result of policy statements by the Reagan administration in October 1981, reprocessing has again become a politically acceptable alternative for spent-fuel disposition in the United States. Efforts are now being made by both government and private interests to overcome the institutional and economic barriers that still face commercial reprocessing.

For all reprocessing and recycling scenarios, it is clear that safeguards and nonproliferation concerns must be actively addressed and sufficient protection provided to reduce risks to acceptably low levels. It is also necessary that any improvement in safeguards be achieved without imposing excessive cost penalties or unrealistic technologic demands.

Recognizing this delicate balance between safeguards risk management and economic viability, EPRI has conducted projects aimed at developing reprocessing and refabrication concepts that meet both objectives. Despite past delays in closing the LWR fuel cycle, within the nuclear industry reprocessing remains the preferred long-term strategy for spent-fuel disposition. For reasons of overall energy resource management, optimization of high-level-waste disposal technology, and linkage of the LWR and breeder reactor fuel cycles, reprocessing and recycling of fissile material from LWRs offer persuasive advantages over direct disposal or indefinite storage of spent fuel.

Before civilian reprocessing or recycling can proceed, facility concepts must be demonstrated that address domestic and international criteria relating to the protection of fissile material. The International Nuclear Fuel Cycle Evaluation (INFCE), completed in 1980, documented an international consensus that an absolute technical fix to prevent illicit use of fissile material was not possible and that a combination of technical and institutional measures would be required. Although no single technical solution was identified, it was concluded that by using diversion-resistant plant designs in conjunction with appropriate operating and accountability procedures, adequate and publicly acceptable levels of protection could be achieved within the framework of an international system for control of fissile material.

EPRI's efforts have been designed to complement the INFCE conclusion by investigating evolutionary reprocessing and refabrication concepts that have the potential for striking an appropriate balance between reducing the safeguards and proliferation risks and maintaining economic and technical viability. The opportunity to make improvements in plant design, however, is constrained by the timeframe in which the plant is expected to be in operation. The timeframes of interest generally place facilities into one of three classes.

The first class consists of facilities that are under construction but that have not yet gone into hot operation. In the United States, the Barnwell (South Carolina) plant of Allied General Nuclear Services is such a facility. For this case, major changes in design concepts cannot be implemented without considerable expense because of the physical constraints imposed by existing structures and equipment. However, the Barnwell plant has been the site of federally sponsored safeguards demonstration programs, and as a result of evolutionary modifications and improvements, it now contains one of the most advanced systems in the world for achieving the objectives of material accountability and diversion resistance. Operation of such facilities will provide necessary confirmation of the capabilities of the new technology for the next generation of facilities.

The second class of facility consists of plants that are designed but not yet built. The nuclear fuel recovery and recycling center (NFRRC) designed by Exxon Nuclear Co., Inc., is an example. Although such a plant incorporates selected advanced technologies based on operating experience and design evolution, the technology can be characterized as being proven or a reasonable extension of existing practice. Such new technologies would not require a great deal of R&D before facility construction and operation. For plants in this stage of development, the cost of incorporating safeguards-related facility, flowsheet, or equipment changes is relatively small.

The third class of plant is the advanced plant. Such facilities now exist only as conceptual designs and often entail the use of more revolutionary technical advancements. Significant R&D is generally required before a final plant design is possible, and a small-scale demonstration facility is normally planned as part of the overall implementation strategy. In the United States, the development work being done at Oak Ridge National Laboratory on advanced breeder and LWR reprocessing concepts, especially robotic and remote maintenance concepts, is illustrative of such advanced technology.

EPRI's work has been directed mainly at the second class of facility, where there is an opportunity for both reasonable change and near-term implementation. Although EPRI keeps up-to-date on work on both the Barnwell reprocessing facility and advanced reprocessing concepts, the primary effort has involved the development of evolutionary reprocessing and refabrication plant designs by Exxon (RP1578-2).

Exxon has used its existing NFRRC reprocessing plant design as a reference and has incorporated new specific design features, including a refabrication plant. The result is a facility with a capacity of about 1500 tons a year that meets expected future safety, occupational exposure, and diversion resistance criteria. These more-demanding design objectives have been met by using existing technology and without incurring unreasonable added costs. (The added costs are estimated to be less than 10%.) The new plant design, which has been named SAFAR for safeguarded fabrication and reprocessing, uses a modified Purex flowsheet. (The Purex process uses a series of solvent extraction operations to effect a separation of the valuable uranium and plutonium from the fission products.)

A layout of the proposed SAFAR facility is shown in Figure 1. Major design improvements were obtained by reducing the number of processing operations by one-third, by reducing the cleanout inventory of fissile material in the continuous-processing portion of the plant by at least an order of magnitude, and by changing the plant layout to achieve improved control over personnel access. The plant material accounting areas, along with the expected operating plutonium inventories and plutonium flows, are shown in Figure 2.

The improved plant design was found to meet all Nuclear Regulatory Commission and International Atomic Energy Agency safeguards criteria and proposed long-range goals with one exception, which involves the ability to detect a 2-kg plutonium loss over a period of up to one year. At present, this goal is concluded to be impractical in any large-scale plant because the required precision in analytic methods is greater than that currently achieved by the National Bureau of Standards in preparing plutonium standards.

As part of the Exxon work, a methodology was developed for semiquantitative evaluation of the diversion resistance of specific plant design features. This was used as a basis for judging trade-offs to improve plant design and diversion resistance. Also, alternative methods of mixed-oxide conversion and fuel rod loading were identified that appear to improve the plant's fissile material control capability.

Through the SAFAR plant concept, this project has identified a practical technical basis for proceeding with closure of the nuclear fuel cycle. Fuel cycle closure has the potential for reducing the storage requirements for spent nuclear fuel, as well as permitting the recycling of valuable residual fissile material. In the long term, such a strategy for spent-fuel disposition can reduce overall nuclear power generation costs, aid in the disposition of high-level waste, and extend the nation's fuel resource base. This study should be of particular value to utilities evaluating long-range fuel disposition strategies. *Project Managers: Ray W. Lambert and Robert F. Williams*

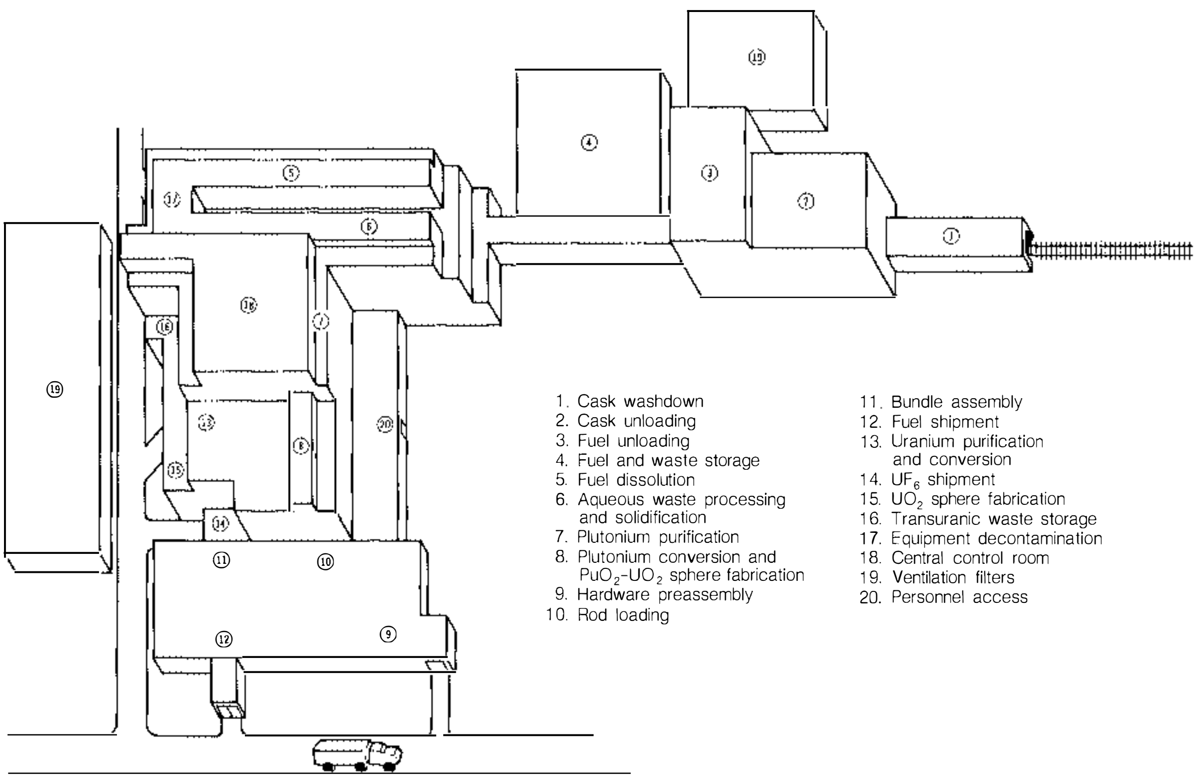
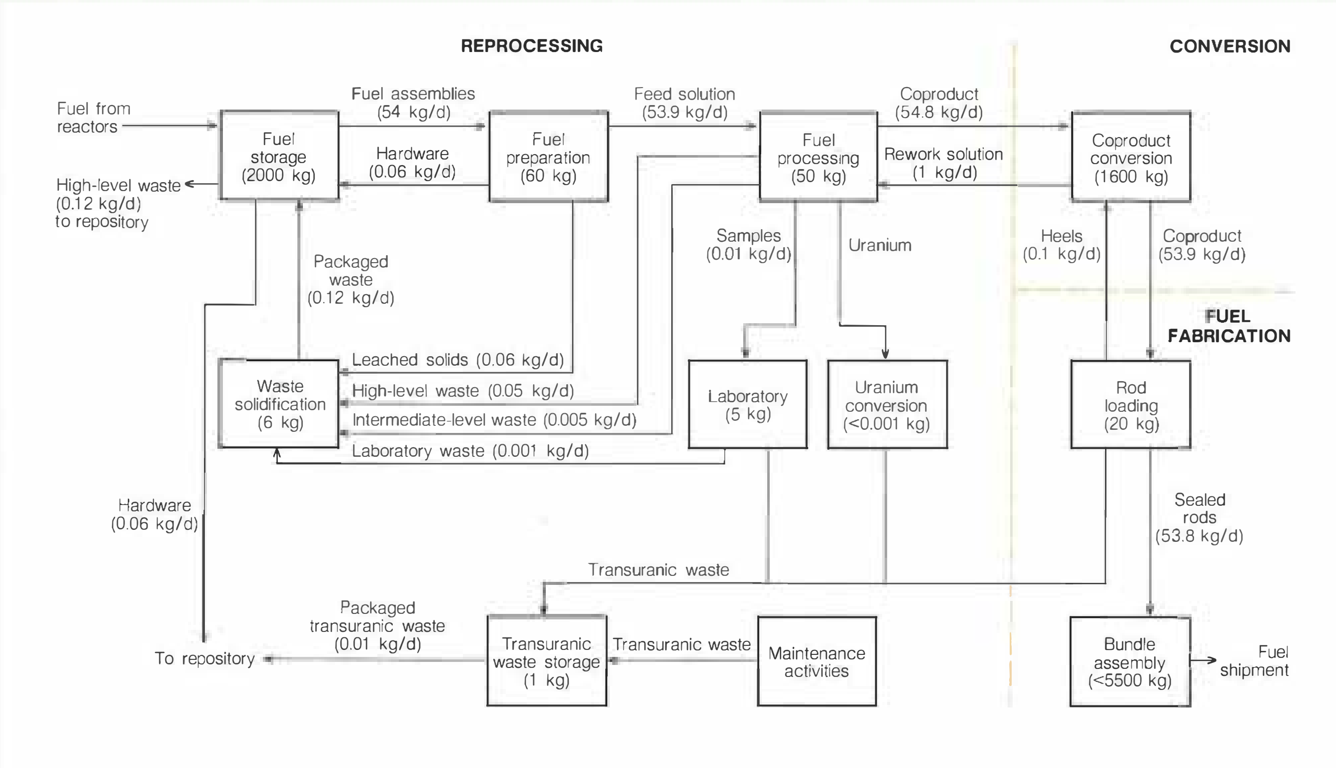


Figure 1 Proposed SAFAR facility for fuel reprocessing and refabrication. This layout minimizes the number of processing steps and reduces employee access to special nuclear materials.

Figure 2 Internal material accountability areas of the SAFAR plant, along with the principal transfers and inventories of plutonium. The plant is designed to permit rapid and accurate inventorying of special nuclear materials. This minimizes plant downtime, while meeting the rigid requirements for material accountability.



New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1607-2	Photovoltaic Concentrator Performance Evaluation	18 months	36.3	Pacific Gas and Electric Co. *R. Taylor*
RP1671-3	Geopressured Resources: Recent Data and Reevaluation	6 months	112.0	Southwest Research Institute *E. Hughes*
RP2029-11	Determination of Year-by-Year Power Plant Capacity Factors	3 months	40.3	Zaininger Engineering Co. *B. Louks*
RP2197-1	Integrated Photovoltaic Central Station Conceptual Designs	13 months	293.8	Black & Veatch Consulting Engineers *R. Taylor*
Coal Combustion Systems				
RP979-14	Parametric Tests: Pressurized Fluidized-Bed Combustor Materials	4 months	207.1	General Electric Co. *J. Stringer*
RP1129-9	Economics of Fabric Filters and Electrostatic Precipitators	15 months	142.6	Stearns-Roger Engineering Corp. *R. Carr*
RP1260-30	Development of an Ash Utilization Program for Highways, Parking Lots, and Utility Construction	4 months	47.9	GAI Consultants, Inc. *D. Golden*
RP1263-9	Portable Gas Chromatograph for Polychlorinated Biphenyl Analysis	7 months	46.6	S-Cubed *R. Komai*
RP1266-30	Japanese Study Mission, Phase 1	5 months	45.9	Ramco, Inc. *A. Armor*
RP1402-13	Fabric Filter Dustcake Fundamental Analysis	10 months	69.1	Southern Research Institute *R. Carr*
RP1645-8	Technical and Cost Evaluation of Alternative Pressurized Fluidized-Bed Combustion Demonstration Plant Applications	5 months	49.9	Gilbert Associates, Inc. *S. Drenker*
RP1860-4	Atmospheric Fluidized-Bed Combustion Dynamic Modeling and Analytic Control Design	7 months	105.1	Babcock & Wilcox Co. *W. Howe*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Electrical Systems				
RP850-32	Field Demonstration of Communication Systems for Distribution Automation, Phase 2	17 months	538.2	Westinghouse Electric Corp. *W. Blair*
RP1277-9	Hurricane Field Development	6 months	38.6	VTC, Inc. *P. Landers*
RP1591-1	AC Field Effects	16 months	198.1	General Electric Co. *J. Dunlap*
RP1712-5	Power Systems Static Security Analysis and Demonstration	33 months	2154.4	ESCA Corp. *C. Frank*
RP1737-2	Power Plant Performance Instrumentation, Scoping Study 2	7 months	166.0	Babcock & Wilcox Co. *J. Lamont*
RP2115-6	Formation of Amorphous Metal by Hypervelocity Impact	6 months	100.0	University of Texas *M. Rabinowitz*
RP2239-1	Development of Improved Lineman's Protective Equipment, Phase 1	8 months	127.5	Battelle, Columbus Laboratories *R. Tackaberry*
RP2308-1	Generator Model Development From Standstill Frequency Response Tests	4 months	40.2	Power Technologies, Inc. *J. Edmonds*
Energy Analysis and Environment				
RP1634-1	Analytic Methods Used Outside the Electric Utility Industry	11 months	198.8	Booz, Allen & Hamilton, Inc. *D. Geraghty*
RP1808-3	Load Duration Curves in an Analytic Form	11 months	98.5	Pacific Gas and Electric Co. *J. Delson*
RP1813-2	Deposition of Sulfur Dioxide on Forests	27 months	332.2	Department of Energy *J. Huckabee*
RP1981-10	Regional Utility Fuel Markets	5 months	146.6	Charles River Associates, Inc. *J. Platt*
RP2070-1	Risk-Benefit Modeling Under RCRA	1 year	134.0	Battelle, Pacific Northwest Laboratories *R. Wyzga*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2174-2	Regional Integrated Lake-Watershed Acidification Study (RILWAS)	30 months	363.7	Wisconsin Department of Natural Resources *R. Goldstein*
RP2174-9	Reconstruction of pH Histories of 10 RILWAS Lakes	18 months	65.9	Indiana University Foundation *R. Goldstein*
RP2198-1	Attenuation Rates, Coefficients, and Constants in Leachate Migration	8 months	161.7	Battelle, Pacific Northwest Laboratories *I. Murarka*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1041-10	Site-Specific Assessment of a 150-MW Coal Gasification–Fuel Cell Power Plant Owned and Operated by Southern California Edison Co.	19 months	118.0	Kinetics Technology International Corp. *D. Rastler*
RP1041-11	Site-Specific Assessment of a Fixed-Bed Coal Gasification–Gas-Cooled Fuel Cell Power Plant Owned and Operated by the City of Santa Clara, California	7 months	62.9	Kinetics Technology International Corp. *D. Rastler*
RP1041-12	Evaluation of Internal Reforming Molten Carbonate Fuel Cell	6 months	149.9	Energy Research Corp. *E. Gillis*
RP1201-26	Assess R&D Needs and Develop Program Plan for Commercial Sector	7 months	58.8	Enviro-Management and Research, Inc. *A. Lannus*
RP1676-4	Selection of Closoboranic Acid Electrolytes for Fuel Cells	9 months	81.4	EIC Laboratories, Inc. *J. Appleby*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP810-12	Technical Support for Soil-Structure Interaction Experiments	5 months	28.6	Applied Research Associates, Inc. *K. Winkleblack*
RP819-2	BWR Radiation Buildup Analysis	14 months	303.6	General Electric Co. *M. Naughton*
RP889-4	RETRAN Design Review	4 months	40.0	Energy Incorporated *L. Agee*
RP1398-11	Weld Repair of Turbine Rotors	5 months	32.4	Failure Analysis Associates *F. Gelhaus*
RP1560-1	PWR Waste Gas System Analysis	8 months	75.7	EDS Nuclear, Inc. *M. Naughton*
RP1572-5	Workscope for Valve and Piping Analysis	3 months	123.8	Continuum Dynamics, Inc. *A. Singh*
RP1935-3	Wear of High-Cobalt Alloys in Valves	1 year	46.5	Westinghouse Electric Corp. *H. Ocken*
RP2058-8	Effects of Impurities and Grain Size on Irradiation-Assisted Intergranular Stress Corrosion Cracking of Types 304 and 348 SS	15 months	170.4	Technology Program Development *A. Giannuzzi*
RP2122-6	Analysis of Thermal Mixing With the PHOENICS Code	6 months	26.0	CHAM of North America, Inc. *J. Sursock*
RP2122-8	Improved Differencing Scheme in the COMMIX-1A Computer Program	6 months	130.6	Babcock & Wilcox Co. *J. Kim*
RP2165-2	Evaluation and Development of Improved Crack Detection Techniques	9 months	120.4	Westinghouse Electric Corp. *J. Quinn*
RP2170-4	Hazard Identification for Nuclear Plant	5 months	47.7	Boeing Aerospace Co. *D. Worledge*
RP2183-2	Impact of Standard Technical Specifications on Plant Availability and Safety	2 months	30.1	NUS Corp. *J. Matte III*

R&D Staff

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2257-1	Grain Boundary Composition and Intergranular Fracture of Steels	40 months	310.0	Battelle, Pacific Northwest Laboratories *R. Viswanathan*
RP2260-2	Reliability of SiC in Combustion Environment	35 months	190.0	Pennsylvania State University *W. Bakker*

New Technical Reports

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

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

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ADVANCED POWER SYSTEMS

1-MW (th) Solar-Thermal Conversion Full-System Experiment

AP-2435-SY Summary Report (RP1509-1); $9.00

Phase 1 of this project is reviewed, which involved the planning and design of a complete Brayton-cycle solar central receiver experimental system. Each of the major subsystems in this solar-fossil hybrid concept is described, including the digital control and data collection subsystems. The estimated operating capabilities of the system are outlined, along with the test and operating plans. Fabrication and testing will be conducted in Phases 2 and 3. The contractor is Boeing Engineering & Construction. *EPRI Project Manager: J. E. Bigger*

Design Strategy for the Combustion of Coal-Derived Liquid Fuels

AP-2517 Interim Report (RP1412-6); $16.50

This report presents the results of experiments to determine the amenability of SRC-II coal-derived liquid fuels to combustion-process modification by air staging for NO_x and particulate emission control. Two experimental systems were used: a laboratory-scale laminar flow reactor (drop-tube furnace) and a 3-MW(th) combustion furnace. The contractor is the Massachusetts Institute of Technology. *EPRI Project Manager: W. C. Rovesti*

Materials for Syngas Coolers

AP-2518 Final Report (RP1654-5); $16.50

This report describes an investigation of the behavior of metals, alloys, and coatings in syngas coolers of entrained slagging gasifiers. Laboratory experiments were conducted that involved the isothermal exposure of uncooled metal samples in a simulated coal gasification environment with a syngas cooler temperature range of 300–500°C. Materials performance is analyzed in terms of thermodynamic and kinetic considerations, and recommendations for long-term tests and the development of protective coatings are presented. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Manager: W. T. Bakker*

Evaluation of Inertial Confinement Fusion Engineering Opportunities on Existing and Planned Facilities

AP-2521 Final Report (RP1971-1); $16.50

An examination of seven representative reactor designs has identified 97 critical engineering data requirements and 78 associated experiments needed to reduce technical uncertainty. This report includes preliminary plans for 10 of the experiments, covering justification, experimental approach, and requirements for equipment, staffing, and time. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: K. W. Billman*

Coking Properties of Coal Under Pressure and Their Influence on Moving-Bed Gasification

AP-2535 Final Report (RP1267-7); $13.50

This report presents test results on the coking properties of seven bituminous coals being studied with respect to their possible use in moving-bed gasifier systems. It discusses the effects of total pressure, hydrogen partial pressure, heating rate, and the presence of mineral inclusions and tar on the fluidity and swelling properties of each coal. Complete physical, chemical, and petrographic analyses of the coals are also described. The contractor is Conoco Coal Development Co. *EPRI Project Manager: John McDaniel*

Reliability and Availability Assessments of Selected Domestic Combined-Cycle Power-Generating Plants

AP-2536 Final Report (RP1319-6); $12.00

The results of reliability and availability assessments performed at combined-cycle power plants are presented. These assessments evaluated combined-cycle unit equivalent availability and equivalent forced-outage rates; system and component mean time between failures and mean downtime; and gas turbine reliability correlations with service hours, starting frequency, fuel type, and service factor. A data base was developed, and recommendations for improving outage data collection for reliability analysis are given. The contractor is Arinc Research Corp. *EPRI Project Managers: Jerome Weiss and Richard Duncan*

Photovoltaic Field-Test Performance Assessment

AP-2544 Interim Report (RP1607-1); $12.00

This report describes the performance of four flat-plate photovoltaic systems in field tests conducted during 1981. It covers overall system conversion efficiencies, clear-day capacity factors, clear-day energy output, and the power-conditioning subsystems. The contractor is Boeing Computer Services, Inc. *EPRI Project Manager: R. W. Taylor*

Evaluation of Methanol as a Boiler Fuel for Electric Power Generation

AP-2554 Final Report (RP1412-11); $18.00

This report describes a series of full-scale combustion tests in which 406,000 gallons of nominally chemical-grade methanol were burned in a balanced-draft, front-wall-fired boiler designed to generate 425,000 lb/h of steam at 1250 psig and 950°F. These tests were part of an effort to gain information on the handling, combustion, and emissions characteristics of various coal-derived fuels that are potential substitutes for conventional fossil fuels in utility boilers. The tests showed methanol to be a technically viable fuel, but its limited availability and high cost prevent its economical use. The contractor is Southern California Edison Co. *EPRI Project Manager: Henry Schreiber*

Technical Evaluation of Wood Gasification

AP-2567 Final Report (RP986-10); $9.00

This report presents an analysis of the early commercial performance of the Omnifuel biomass gasifier installed at the Levesque plywood plant at Hearst, Ontario, Canada. The gasifier's operability and technical performance are assessed, and recommendations for further investigation are presented. The contractor is Synthetic Fuels Associates, Inc. *EPRI Project Manager: S. M. Kohan*

COAL COMBUSTION SYSTEMS

Amine-Enhanced Photodegradation of Polychlorinated Biphenyls

CS-2513 Final Report (RP1263-6); $9.00

A series of experiments was conducted to demonstrate the practicality of using natural solar radiation in conjunction with the application of an amine for in situ degradation of PCBs in contaminated soil. The results are discussed, and further research needs are delineated. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: R. Y. Komai*

Entrainment in Wet Stacks

CS-2520 Final Report (RP1653-1); $19.50

This report reviews utility industry experience with wet stacks and examines the problem of liquid discharge from stacks. The sources of liquid droplets in a wet stack are identified, along with the critical parameters that must be considered when designing wet stacks. A number of design changes for wet stacks that can potentially enable the collection of entrained liquid droplets are presented. When these design changes are combined with simple techniques to prevent reentrainment, the stack liquid discharge can be significantly reduced. The contractor is Dynatech R/D Co. *EPRI Project Manager: C. E. Dene*

Full-Scale Scrubber Characterization of Conesville Unit 5

CS-2525 Final Report (RP1410-3); $60.00

This report describes the characterization of the Conesville Unit 5 flue gas desulfurization system by field testing and engineering analysis. It includes

(1) a discussion of the scrubber process chemistry based on the system performance data gathered, (2) an assessment of the applicability of measurement techniques and the quality and limitations of the resultant data, and (3) an engineering and economic analysis of the scrubber, along with suggested improvements to the system. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Manager: R. G. Rhudy*

Condensation in Steam Turbines

CS-2528 Final Report (RP735-1); $12.00

This report presents the Phase 1 results of a project to obtain data on the fundamental mechanics of steam turbine condensation. A unique nucleation tube concept and the two-wavelength laser attenuation measurement technique were used. Details are included on the thermodynamic location of the Wilson point, moisture droplet size, and droplet growth history in an environment that closely duplicated the pressures, temperatures, and expansion rates found in actual turbine stages. The contractor is General Electric Co. *EPRI Project Managers: T. H. McCloskey and J. B. Parkes*

Literature Review of FGD Construction Materials

CS-2533 Final Report (RP1871-1); $21.00

A survey of the literature on corrosion-related failures in flue gas desulfurization (FGD) systems is presented. The survey covers materials used in pilot and full-scale FGD systems, as well as applicable materials experience in other industries. The report addresses (1) corrosion failure mechanisms and common means of measuring susceptibility to each, (2) alloys and coatings and the effect of different alloying elements, and (3) field experience with different materials in each section of an FGD system. The contractor is Battelle, Columbus Laboratories. *EPRI Project Managers: C. E. Dene and B. C. Syrett*

Materials Testing in Simulated Flue Gas Desulfurization Duct Environments

CS-2537 Final Report (RP1871-1); $10.50

This report presents results from a laboratory evaluation of candidate alloys and coatings exposed to corrosive conditions in simulated outlet duct environments in wet flue gas desulfurization systems. Data are provided on the performance of (1) stainless steels and nickel alloys with varying amounts of molybdenum, and (2) coatings made of organic and inorganic materials currently being recommended for scrubber service, including trowel-applied types, spray-on vinyl esters, cements, neoprene, and a natural rubber. The contractor is Battelle, Columbus Laboratories. *EPRI Project Managers: C. E. Dene and B. C. Syrett*

Manual for Upgrading Existing Disposal Facilities

CS-2557 Final Report (RP1685-2); $37.50

This report presents background information and guidance for the utility engineer in upgrading waste disposal sites. Current regulatory requirements for land disposal of nonhazardous utility wastes and potential problems with land disposal are discussed. The manual presents detailed engineering data on available site-upgrading techniques, as well as a comparative cost analysis of upgrading alternatives. The contractor is SCS Engineers. *EPRI Project Manager: D. M. Golden*

Stochastic-Convective Ensemble Method for Representing Dispersive Transport in Groundwater

CS-2558 Topical Report (RP1406-1); $12.00

This report discusses the development of a stochastic-convective transport method to describe three-dimensional hydrodispersion of a nonreactive solute in groundwater. The application of the method to a small-scale tracer experiment is presented. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: D. M. Golden*

ELECTRICAL SYSTEMS

Research to Develop Guidelines for Cathodic Protection of Concentric Neutral Cables

EL-1970 Final Report, Vol. 3 (RP1049-1); $22.50

This volume presents guidelines for the installation of cathodic protection systems on direct-buried concentric neutral cables. Detailed design, installation, and maintenance recommendations for cathodic protection systems are included. The contractor is Pacific Gas and Electric Co. *EPRI Project Manager: T. J. Kendrew*

Modeling of Unit Operating Considerations in Generating Capacity Reliability Evaluation

EL-2519 Final Report (RP1534-1); Vol. 1, $21.00; Vol. 2, $12.00

This report identifies operating characteristics that influence generation system reliability; discusses the development and validation of a Monte Carlo simulation model, GENESIS, for calculating reliability indexes; addresses the development of analytic methods for modeling the operating characteristics; identifies potential model applications; and defines the data requirements. Volume 1 contains the mathematical models, computing methods, and results. Volume 2 presents the computer code program documentation. The contractor is Associated Power Analysts, Inc. *EPRI Project Manager: N. J. Balu*

Calibration of Power System Simulation Programs, Using Disturbance Data

EL-2532 Final Report (RP1469-2); $21.00

This report reviews utility practices and developments in the calibration of transient stability and long-term dynamic simulation programs; these programs are then compared with data recorded during a major system disturbance. The report describes models representing the disturbance behavior of various system components, procedures that have been used for recording long-term dynamic response of variables, and areas needing further development. The contractor is ESCA Corp. *EPRI Project Managers: J. V Mitsche and J. W. Lamont*

Carrier Frequency Noise From HVDC Converters

EL-2545 Final Report (RP1427-1); $25.50

This report describes the development of an ac- and dc-side carrier frequency noise model for incorporation in Bonneville Power Administration's electromagnetic transient program. The model representation of HVDC equipment, such as converter transformers, smoothing reactors, and harmonic filters, is compared with deenergized impedance measurements of similar equipment in an HVDC station. Measurement methods are discussed. The contractor is General Electric Co. *EPRI Project Managers: John Reeve and Gilbert Addis*

Effect of Distributed Power Systems on Customer Service Reliability

EL-2549 Proceedings (TPS79-759); $12.00

This report discusses the energy supply reliability aspects of distributed power systems (DPSs). A variety of analytic methods for studying DPS reliability are addressed, and the significant impact on reliability of backup systems, such as storage devices, fuel cells, or a utility network, is discussed. Suggestions for further research are given. The contractor is Systems Control, Inc. *EPRI Project Managers: N. J. Balu and O. S. Yu*

Electric Generation Expansion Analysis System

EL-2561 Final Report (RP1529-1); Vol. 1, $24.00; Vol. 2, $18.00

This report details the development and use of the Electric Generation Expansion Analysis System (EGEAS), a modular, state-of-the-art capacity expansion software package. Volume 1 describes the structure and capabilities of EGEAS and presents the results of a testing and validation effort. Volume 2 presents mathematical appendixes and a detailed description of the three generating systems used in testing and validating EGEAS. The contractor is the Massachusetts Institute of Technology. *EPRI Project Manager: N. J. Balu*

Flexible Gas-Insulated Metal-Enclosed Transmission System Design

EL-2563 Final Report (RP7837-1); $15.00

This report describes the development of flexible gas-insulated cable for power transmission applications from 138 to 345 kV. An 80-m length of prototype 345-kV, 1000-MVA cable was manufactured, tested, and shipped to the Waltz Mill (Pennsylvania) Underground Cable Test Facility for long-term testing. The development of a machine to continuously produce corrugated tubing is also described, and a series of tables and graphs is presented to aid in determining current-carrying capacity under various conditions for aboveground and underground installations. The contractor is Brown Boveri Electric, Inc. *EPRI Project Manager: R. W. Samm*

Proceedings: 1981 PCB Seminar

EL-2572 Proceedings (WS81-244); $27.00

This report contains the proceedings of an EPRI seminar held in December 1981 in Dallas, Texas, that focused on emerging technologies and ideas for polychlorinated biphenyl analysis and removal. The major areas covered were background of the problem, analytic techniques, spill cleanup, destruction of askarels, treatment of capacitors, and decontamination of oil. *EPRI Project Manager: Gilbert Addis*

HVDC–AC System Interaction From AC Harmonics

EL-2583 Final Report (RP1138-1); Vol. 1, $27.00; Vol. 2, $15.00

This report summarizes impedance-frequency characteristics measured on an ac system serving an HVDC converter and compares these characteristics with values obtained by using a digital model. Two methods of calculating system harmonic impedances are discussed—an analytic method and a measurement method—and computer programs for both are presented. Volume 1 reports on the technical approaches and results. Volume 2 documents the computer programs. The contractor is General Electric Co. *EPRI Project Managers: Gilbert Addis and N. G. Hingorani*

ENERGY ANALYSIS AND ENVIRONMENT

Sulfate Regional Experiment: Data Base Inventory and Summary of Major Index File Programs
EA-1904 Interim Report (RP862-2); $12.00

This report describes in detail the composition and format of the SURE data base. Included are a listing of the percent data capture of currently available validated data by site and month, a summary of major files and programs used to access and manipulate the data, and a format description of all data files incorporated into the data base. Four categories of data are available: ground station-monitored air quality data, aircraft-monitored air quality data, upper-air and surface meteorological observations, and the emissions inventory compiled for the SURE region. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: G. R. Hilst*

Sulfate Regional Experiment: Regional Air Quality Modeling Documentation
EA-1907 Interim Report (RP862-2); $16.50

This report provides detailed documentation of the SURADS (sulfate regional advection and diffusion scheme) model, a regional air quality model developed for the SURE project. It describes important features of three components of the model—the meteorologic discretization system, the air quality initialization system, and the numerical integration system. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: G. R. Hilst*

PILOT-1980 Energy-Economic Model: Operator's Guide
EA-2090 Interim Report, Vol. 2 (RP652-1); $25.50

This volume presents a programmer's and operator's guide to the set of computer programs that embody the PILOT model, a long-range optimization model that interfaces a detailed representation of the energy sector with a less detailed representation of the rest of the economy. A brief overview of the model's three stages—matrix generation, optimization, and report writing—is presented, followed by a more detailed description of the several computer programs. The contractor is Stanford University. *EPRI Project Manager: S. K. Mukherjee*

World Oil
EA-2447-SY Summary Report (RP875-1–8); $13.50

Issues relating to oil price, availability, and security of supply were addressed by Energy Modeling Forum members from around the world by applying 10 models to 12 scenarios. The report examines potential price jumps during oil supply interruptions, evaluates how these escalations could be moderated, and estimates the oil market impacts of different unconventional fuel supply levels after the year 2000. The contractor is Stanford University. *EPRI Project Manager: S. K. Mukherjee*

Response of Agricultural Soils to Acid Deposition
EA-2508 Proceedings (RP1904-1); $13.50

This report contains the proceedings of an EPRI-sponsored workshop held in May 1981 in Columbus, Ohio, that evaluated the potential beneficial and harmful impacts of atmospheric acid deposition on agricultural soils. Those issues requiring further research are identified. Five working papers and a literature review prepared by soil specialists are presented, along with a summary of conclusions reached by the participants. The contractor is Battelle, Columbus Laboratories. *EPRI Project Managers: J. W. Huckabee and P. K. Mueller*

Proceedings: End-Use Models and Conservation Analysis
EA-2509 Proceedings (RP1050); $49.50

This report contains papers presented at an EPRI workshop held in November 1980 in Atlanta, Georgia, to review recent developments in end-use models of energy consumption. The papers cover the commercial, industrial, and residential sectors. The contractor is the University of Arizona Engineering Experiment Station. *EPRI Project Manager: Ahmad Faruqui*

Solid-Waste Environmental Studies: Needs and Priorities
EA-2538-SR Special Report; $9.00

This report presents the rationale for a research program on the effects of solid-waste disposal on groundwater quality. Problem areas considered are inorganic heavy metals, other inorganic elements, organic substances, and dissolved substances. Research needs common to all four areas are identified, along with specialized research requirements. The research projects required to meet the electric utility industry's needs during the next five years are discussed and ranked in order of importance. *EPRI Project Manager: I. P. Murarka*

Acid Deposition: Decision Framework
EA-2540 Final Report, Vol. 1 (RP2156); $12.00

This volume explains decision analysis methods and presents a framework for analyzing decisions about acid deposition. The state of scientific information and the modeling assumptions of the framework are discussed in reference to its three main modules. Two versions of a decision tree model for implementing the framework are given, and illustrative data and calculations using the decision tree models are presented. The contractor is Decision Focus, Inc. *EPRI Project Manager: R. G. Richels*

Coal Slurry Pipelines: Review and Analysis of Proposals, Projects, and Literature
EA-2546 Final Report (RP1219-5); $21.00

This report analyzes coal slurry pipelines from an electric utility perspective, addressing such issues as cost inflation, water availability, regulation, and gathering and distribution systems. It covers both engineering aspects (construction and engineering costs scaled for application to any pipeline) and financial aspects (based on long-term asset selection criteria under a number of regulatory, participation, and financial scenarios). Areas for additional utility research are suggested. The contractors are Michael Rieber and Shao Lee Soo. *EPRI Project Manager: E. G. Altouney*

Heuristic Analysis of Industry and Economic Effects of Restrictions on Generating Capacity
EA-2552 Final Report (RP1152); $12.00

This report presents a simple heuristic model to approximate the full-scale computer modeling system used in an earlier study to analyze the effects of generating capacity restrictions on the electric power industry, the energy sector, and the economy. (The full-scale system combined the Hudson-Jorgenson long-term interindustry transaction model and the Baughman-Joskow regionalized electricity model.) The quantitative results for eight policy cases previously studied are replicated, and the application of the simple model to a new problem is illustrated. The contractor is Dale W. Jorgenson Associates. *EPRI Project Manager: H. P. Chao*

Mathematical Generation Planning Models Using Decomposition and Probabilistic Simulation
EA-2566-SR Special Report; $28.50

This report describes a global mathematical programming technique (based on the generalized Benders method) that rigorously treats the nonlinearities introduced by probabilistic representation of generator forced outages. The report discusses recent refinements of the technique, involving production costing; convergence limits that speed calculation; inclusion of hydroelectric and limited energy storage plants; and inclusion of wind, solar, and other renewable technologies. *EPRI Project Manager: J. K. Delson*

Evaluation of Existing Programs for Simulation of Residential Building Energy Use
EA-2575 Final Report (RP1775-1); $21.00

Various analytic methods of estimating residential energy use are classified, and commonly used thermal-load algorithms are discussed. Five selected models were tested against high-quality metered data. Limits to the predictive capabilities of residential building energy analysis programs are identified, and the role of the analyst in program accuracy is explored. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: Edward Beardsworth*

ENERGY MANAGEMENT AND UTILIZATION

Computer Code for Prediction of Reliability and Available Capacity of Modular Energy Storage Arrays
EM-2486 Final Report, Vol. 1 (RP370-17); $7.50

This volume addresses the reliability of modularized energy storage arrays and documents the computer programs developed for estimating reliability performance measures. It discusses the combination of mathematical modeling and Monte Carlo simulation used for array reliability analysis, and describes the incorporation of a dynamic memory allocation scheme and a string balancing option into the computer codes. The contractor is Science Applications, Inc. *EPRI Project Manager: W. C. Spindler*

Molten Carbonate Fuel Cell System Verification and Scale-up

EM-2502 Interim Report (RP1273-1); $12.00

This report describes progress in a four-year project to demonstrate operation of a subscale breadboard molten carbonate fuel cell power plant at conditions that accurately simulate utility power plant operation. The goals of the work reported here were to design and verify a fuel cell stack configuration capable of being operated at pressure and incorporating provisions for interfacing with thermal-, reactant-, and electrolyte-management systems required in a power plant. Results of a 3000-hour test of a 10-cell stack at pressure are discussed. The contractor is United Technologies Corp. *EPRI Project Manager: E. A. Gillis*

Evaluation of Industrial Advanced Heat Recovery/Thermal Energy Storage Systems

EM-2573 Final Report, Vol. 1 (RP1275-1); $9.00

This volume presents an executive summary of an investigation of the potential benefits of installing waste heat recovery systems. Plant and process energy data acquired during visits to 12 industrial plants are discussed, as are cost and performance data for commercially available (1985) equipment. The potential economic benefits, energy savings, and utility impacts of the proposed systems are addressed. The contractor is United Technologies Corp. *EPRI Project Manager: I. L. Harry*

Development of Advanced Batteries for Utility Application

EM-2579 Final Report (RP128-6); $21.00

The interim results of a program to develop beta (sodium-sulfur) batteries for utility load-leveling applications are presented; the reporting period was June 1979–June 1981. The major accomplishments of the program are detailed, including the design of a utility-sized cell and work on a beta″-alumina electrolyte. Other efforts involved the further development of protective coatings for the sulfur electrode, the design of cell seals, and the development of testing facilities. The contractor is General Electric Co. *EPRI Project Manager: James Birk*

NUCLEAR POWER

BWR Refill-Reflood Program 30° Sector Experimental Task Plan

NP-1525 Interim Report, Vol. 5 (RP1377-1); $7.50

This report presents the experimental task plan for the CCFL/refill system effects tests (30° sector) of the BWR Refill-Reflood Program. This volume provides the test matrix for the loss-of-coolant accident simulation with the BWR/4 emergency core cooling systems. Test objectives, conditions, and operating procedures are summarized. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

BWR Refill-Reflood Program 30° SSTF Facility Description

NP-1584 Interim Report (RP1377-1); $16.50

This report documents the refill-reflood 30° steam sector test facility, a large-scale facility simulating a BWR. Descriptions are provided of the design objectives, the scaling bases for the system and components, the test section and supporting test loop, the measurement system, the data acquisition and reduction systems, and the operating procedures. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

Categorization of Cable Flammability: Intermediate-Scale Cable Tray Fire Tests

NP-1881 Interim Report (RP1165-1); $15.00

This report summarizes a project to provide an improved quantitative understanding of the fire-related characteristics of electrical cables installed in grouped cable trays. Seven free-burn tests and 10 extinguishment tests were conducted on intermediate-scale cable tray installations. Complex interrelationships between the test parameters—such as cable types, cable loading arrangements, and tray configurations—and the resulting free-burning fire intensities are discussed. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: Joseph Matte III*

STEALTH: A Lagrange Explicit Finite Difference Code for Solids, Structural, and Thermohydraulic Analysis

NP-2080-SY Computer Code Manual (RP307-1); $25.00

NP-2080 Computer Code Manual, Vols. 1A, 1B, 2, and 3; $150.00 (per set)

The summary volume (NP-2080-SY) presents an overview of STEALTH, gives instructions on how to use the code, and provides information about where to find more detailed documentation. Volumes 1A and 1B are user's manuals. The former contains theoretical background material and numerical equations; the latter, STEALTH input instructions. Volume 2 presents sample and verification problems to help users become familiar with STEALTH capabilities and input and output. Volume 3 is a programmer's manual. The contractor is Science Applications, Inc. *EPRI Project Managers: Conway Chan and H. T. Tang*

Effect of Moisture Separator Drain Routing on OTSG Secondary-System Chemistry

NP-2505 Topical Report (RP704-1); $9.00

This report presents the results of recent studies on the effects of moisture separator drain routing in PWR nuclear power plants with once-through steam generators (OTSGs). The transport of various impurities and corrosion products to OTSGs is discussed, and a solution is proposed that entails routing some of the moisture separator drain flow to the condenser to reduce the amount of impurities. The contractor is NWT Corp. *EPRI Project Manager: G. W. DeYoung*

Guidebook for ENDF/B-V Nuclear Data Files

NP-2510 Topical Report (RP975-1); $46.50

This report is a convenient reference and guide to nuclear data derived from the Evaluated Nuclear Data File, Version V (ENDF/B-V). Plots of the major cross sections for each of the nuclides in the general purpose file are included, and a comparison of cross-section ratios is provided for the major fissile nuclei. A table of nuclide properties derived from data files is presented, and the contents of the complete ENDF/B-V library are outlined. The contractor is Brookhaven National Laboratory. *EPRI Project Manager: Odelli Ozer*

Two-Phase Friction Multiplier Correlation for High-Pressure Steam-Water Flow

NP-2522 Interim Report (RP813); $15.00

This report describes a two-phase friction multiplier developed as a function of pressure, quality, and mass flux and designed for use in homogeneous two-phase flow models. The steam-water data from the open literature that were used to develop the friction multiplier correlation are summarized. Calculation of the frictional component is described, and the correlation is compared with diabatic data and with several other friction multiplier correlations. The contractor is Columbia University. *EPRI Project Manager: Mati Merilo*

Value-Impact Methodology for Prioritization of Reactor Safety R&D Projects

NP-2530 Final Report (RP1810-2); $15.00

This report describes the development, application, and evaluation of value-impact analysis (VIA) for selecting and ranking reactor safety R&D projects. Application of the VIA approach to four sample projects is detailed. The strengths, weaknesses, and range of VIA are discussed, and a procedures guide for applying VIA to nuclear safety R&D projects is presented. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: A. G. Adamantiades*

Intergranular Stress Corrosion Cracking of Austenitic Stainless Steels in PWR Boric Acid Storage Systems

NP-2531 Interim Report (RP1166-1); $15.00

This report reviews available literature on the intergranular stress corrosion cracking (IGSCC) of austenitic stainless steels at temperatures below 100°C. In addition, it presents the results of experiments that investigated the IGSCC of type-304, type-304L, and type-316L stainless steels in boric acid environments of the type used in PWRs for nuclear shim control. The contractor is Ohio State University. *EPRI Project Manager: M. J. Fox*

PWR Steam-Side Chemistry

NP-2541 Final Report (RP699-1); $24.00

This report summarizes research to determine the causes of denting-type corrosion in steam generators and to assess the efficiency of denting inhibitors. It defines the effects of seven factors on corrosion rates: chloride concentration, reducible metal concentration, temperature, pH, iron sulfate, crevice filler, and crevice geometry. Mathematical models for predicting the denting behavior of isothermal capsules are presented, and a series of heat flux tests is described. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. P. N. Paine*

Remote Detection of Degradation of Fire-Resistant Fluid Lubricants

NP-2543 Interim Report (RP893-1); $10.50

This report documents a study to identify, review, and rank existing and innovative methods for the remote monitoring of lubricant degradation in reactor coolant pump motors. The results of a preliminary experimental evaluation of three techniques—absorption spectroscopy measurement, detection of corrosive attack on copper, and measurement of fluid resistivity—are presented. Recommendations are made for further research on a technique that directly measures acidity. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Joseph Matte III*

Full-Scale Controlled Transient Heat Transfer Test Data Analysis

NP-2547 Final Report (RP494-1); $22.50

Data from previously conducted transient critical heat flux (CHF) experiments (described in NP-1793 and NP-1810) were analyzed by using a bundle average code (MAYU 4) and a subchannel code (COBRA IV). The ability of several CHF correlations to describe the data is examined. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Mati Merilo*

Assessment of Effects of Fort St. Vrain HTGR Primary Coolant on Alloy 800

NP-2548 Final Report (RP2079-1); $15.00

This report presents a review of primary helium coolant chemistry data based on (1) current and past operating experience with high-temperature gas-cooled reactors (HTGRs), and (2) present and expected values for the Fort St. Vrain HTGR. The impact of the expected Fort St. Vrain environment on the material properties of Alloy 800 is discussed, with emphasis on the steam generators. The contractor is General Atomic Co. *EPRI Project Manager: M. E. Lapides*

Valve Stem Packing Improvement Study

NP-2560 Final Report (RP1623-1); $13.50

This report discusses the findings of a survey of valve manufacturers, stem packing manufacturers, and the operators of nuclear power plants. The information obtained is analyzed and evaluated, and recommendations are presented for achieving a stem packing system that would be leak-tight and maintenance-free for a period of at least two years. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: B. P. Brooks*

Electric Generator Monitoring and Diagnostics

NP-2564-SY Final Report (RP970-2); $7.50

This report presents a summary of developmental work on an on-line radio-frequency monitor and a fiber optic temperature sensor for the early detection of equipment failures. The principles and procedures of the laboratory and field tests are briefly discussed; only typical test results are presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: H. G. Shugars*

Two-Phase Performance of Scale Models of a Primary Coolant Pump

NP-2578 Final Report (RP347-1); $15.00

This report documents a study that consolidated data from several experimental programs on two-phase-flow pump performance. The data are analyzed in terms of the homologous curves and the degradation of pump head and torque as a function of inlet void fraction. Existing two-phase pump performance correlations are surveyed, and the results of experiments using a 1/20-scale geometric model of a typical LWR recirculation pump are included. The contractor is Creare, Inc. *EPRI Project Manager: K. H. Sun*

Primer on Colorgraphic Display Systems for Nuclear Power Plants

NSAC-45 Final Report; $12.00

This report provides an overview of the technical issues relating to the application of colorgraphic display systems in nuclear power plants. It covers the NRC emergency response facility requirements, hardware selection criteria and evaluation, theory of operation, host and device independence factors, software engineering, human factors engineering, and serial and parallel interfaces. The primer is intended to be a reference source for utility engineers responsible for system design and software engineering for modern, high-performance computer-based graphic display systems. The contractor is Nuclear Software Services, Inc. *EPRI Project Manager: D. G. Cain*

Evaluation of On-Line Boron Analyzers

NSAC-46 Final Report; $10.50

Testing has been performed to evaluate the performance of three on-line boron analyzers. The tests sought to determine the accuracy of the analyzers, their reliability under normal conditions, their susceptibility to radiation damage, and their accuracy when exposed to high radiation levels. The main objective was to verify the applicability of the instruments for boron analysis under post-accident conditions. The contractor is NUS Corp. *EPRI Project Manager: R. N. Kubik*

Using RETRAN-02 and DYNODE-P to Analyze Steam Generator Tube Breaks

NSAC-47 Final Report; $9.00

Predictions of the RETRAN-02 and DYNODE-P thermal-hydraulic codes were compared against actual plant data from a steam generator tube break incident in October 1979. The results indicate good agreement between the code predictions and actual plant behavior, and the codes have been qualified for use in analyzing steam generator tube breaks. The report provides guidance for code application. *EPRI Project Manager: Jason Chao*

Workshop on Vital DC Power

NSAC-48 Proceedings; $18.00

Because of the importance of the dc power buses that supply instrument and control loads and backup power for other vital functions at nuclear power plants, a two-day workshop on vital dc power was sponsored by NSAC and Commonwealth Edison Co. A number of events caused by dc bus and battery malfunctions were discussed. along with suggestions on how to deal with those events. Instrument and control bus design philosophy, battery charge status, battery care, battery load management, methods of locating dc system grounds, and plant response to dc bus failures were addressed. *EPRI Project Managers: W. B. Reuland and H. L. Wyckoff*

Current Emergency Planning Requirements

NSAC-50 Proceedings; $28.50

This report details the issues considered at a two-day workshop sponsored by NSAC on the relationships between severe accident releases and emergency planning requirements. The topics covered included emergency planning zone size, public alerting and warning requirements, public use of potassium iodide as a thyroid blocking agent, protective actions involving public evacuation and shelter, and economic burdens due to emergency planning. The contractor is Science Applications, Inc. *EPRI Project Manager: R. J. Catlin*

Integrated Data Acquisition System

NSAC-51 Final Report; $25.50

This report describes an integrated data acquisition system for providing data for various main information-processing computers at a nuclear plant. The focus is on interfacing a modern distributed multiplexing data system with an existing plant control and instrument system. The document is intended to be a reference for utilities planning to retrofit and upgrade plant information systems. The contractor is Roy & Associates, Inc. *EPRI Project Manager: D. G. Cain*

BWR High-Pressure Core Cooling

NSAC-53 Final Report; $9.00

This report examines the problem of high-pressure coolant injection (HPCI) systems and reactor core isolation cooling (RCIC) systems in BWR plants not meeting HPCI and RCIC performance goals for core cooling. The impact of a high-quality preventive maintenance program is determined, such a program is reviewed, and the importance of cold quick-start testing for assessing the correct functioning of all components, control systems, and instruments is addressed. *EPRI Project Manager: R. O. Brugge*

Using PRA to Assess Nuclear Power Plant Operating Events

NSAC-54 Final Report; $13.50

This report describes the computer code SIEVE, an easy-to-use probabilistic risk assessment (PRA) technique capable of calculating core damage probabilities that are adequate for generic comparative purposes. Possible other uses for SIEVE are discussed, such as determining priorities for generic safety issues, aiding in emergency planning studies, and calculating the risk associated with taking equipment out of service for maintenance. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: W. L. Lavallee and W. B. Reuland*

Safety Parameter Display System

NSAC-55 Interim Report; $19.50

This report describes a continuing program to develop the basic elements of the safety parameter display system (SPDS). The design and implementation of a prototype SPDS at an operating power plant are detailed, and its development as an example of a simple and practical retrofit installation is discussed. Work completed during February–September 1981 is reported; functional specifications, display specifications, general system design, and project plans are outlined. The contractors are Yankee Atomic Electric Co. and Technology for Energy, Inc. *EPRI Project Manager: D. G. Cain*

INFORMATION SERVICES

Progress on Significant R&D Projects

RA-2350-SR Special Report; $15.00

This report updates the status of 32 large projects (authorized for $5 million or more); describes 86 smaller projects (authorized for less than $5 million) that are likely to produce a new utility-useful near-term accomplishment in the next two years; and reviews 45 examples of analytic, experimental, and bench-scale projects that were influential in confirming or redirecting EPRI's research program. These examples cover the entire spectrum of electric power R&D. *EPRI Program Manager: W. H. Seden*

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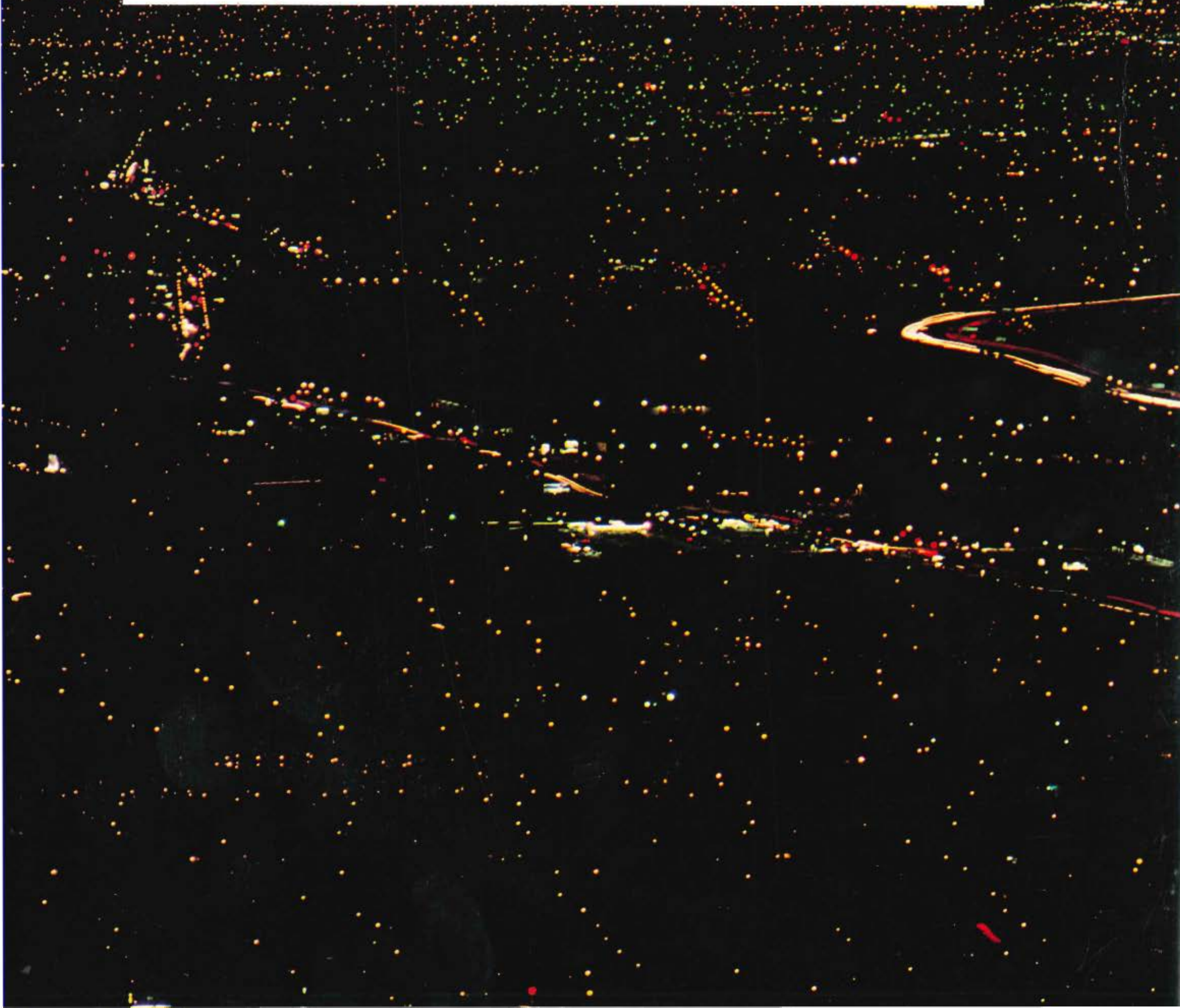

November 1982