The Human Factor

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Cover: Power plant design and engineering encompass more than just inanimate equipment. The humans who operate and maintain plants must also be taken into account.

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Focus on the Human Element

Human resources—the most valuable asset of any enterprise—have become a focal point for industrial improvement in recent years. This trend can be clearly seen in the application of behavioral science findings to industrial management, in the use of quality circles to encourage employee participation, and in increased awareness of the importance of human factors in industrial machinery design and operation. Concern for human factors is especially evident in the nuclear power industry because that industry recognizes the role of the human element in the 1979 Three Mile Island accident.

Prompted by the experiences at Three Mile Island, the nuclear utility industry formed the Institute of Nuclear Power Operations to establish operation and training standards and to monitor utility operations. The nuclear utilities also carried out intensive reviews that have resulted in substantial strengthening of operating practices and procedures. EPRI's efforts in the evaluation and application of human factors engineering were increased, both in design of control room equipment and in maintenance features of all nuclear power plant equipment. For example, a number of guides now available from EPRI provide human factors considerations for utilities, architect-engineers, and industry suppliers to use in the improvement of existing control rooms or the design of new control rooms.

Improved control room instrumentation, including graphic display devices and diagnostic instruments, is another area being developed as a result of R&D by EPRI, individual utilities, and nuclear industry suppliers. For example, a safety parameter display system is now being tested that reduces key safety-related data to a single display with which an operator can locate trouble, access further information, and decide on the action to be taken. A more advanced computer-based diagnostic system, called a disturbance analysis and surveillance system, is also being readied for test. A computerized alarm-handling system developed in Norway is being considered for application in U.S. plants. This system suppresses the many individual signals that can distract an operator during a major abnormal condition and activates only the most significant alarm.

The implementation of these human factors improvements is in itself an important human factors issue. What might appear to be a significant operator aid to the design engineer might not prove to be so in the practical circumstances of an operating control room. The only person who can judge the true benefit of such an aid is the operator. Thus, proposed control room improvements must be thoroughly tested and accepted by operators, preferably in simulator trials, before EPRI considers its research complete.

Most human factors improvements will be made in plants that are already in operation or well under construction. In the interest of continuing safety, a great deal of care must be taken to avoid mistakes in implementing improvements. Operators must be totally familiar with the new equipment so that its initial use does not cause confusion during actual operation. In short, operational continuity must be maintained. NRC recently recognized this need for continuity in establishing new regulations governing control room capability and emergency response. In implementing these new requirements, NRC is working with individual utilities to adjust to plant-specific features and establish modification schedules in order to permit orderly planning and the preservation of the continuity so essential to safe operation.

The increased emphasis on human factors in design, operation, and regulation may well be the most important outcome of Three Mile Island.

John J. Taylor, Director
Nuclear Power Division

Authors and Articles

Knob shape, meter height, light intensity, alarm level, color code—each such characteristic in a power plant control room says something to the operators. **Designing for Man: Advances in Control Room Operation** (page 6) surveys research into these and other design details that influence plant operation and maintenance. Written by Nadine Lihach, the *Journal's* senior feature writer, the article draws on work by four research managers in three departments of EPRI's Nuclear Power Division.

David Cain, manager of diagnostic instrumentation for the Nuclear Safety Analysis Center, has been with EPRI since August 1974. His most recent focus has been the safety parameter display system, which integrates hundreds of plant variables into a compact display. Cain previously worked in the Safety and Analysis Department. From 1971 to 1974 he was with Westinghouse Electric Corp.'s naval reactors division. Cain is an electrical engineer with a BS from the University of California at Berkeley and an MS and a PhD from the University of Washington.

Alexander Long, in the Safety and Analysis Department, is a program manager for analysis and testing requirements. His major work concerns the disturbance analysis and surveillance system, an even more complicated online computer system for monitoring and analyzing safety and availability in nuclear power plants. Before joining EPRI in August 1975, Long was at Argonne National Laboratory for six years, designing and running experiments related to fast breeder reactor design. He has a BS in physics from Williams College and a PhD in nuclear engineering from the University of Illinois.

John O'Brien has been with the Engineering and Operations Department since November 1979, part of that time on loan to the Institute of Nuclear Power Operations but mostly in the System Performance Program, where his research specialty is human factors engineering. For five years before he came to EPRI, O'Brien was with the R&D Center of Westinghouse Electric Corp., where he was principal investigator in research involving man-machine interactions for nuclear power plant control. O'Brien holds BS, MS, and PhD degrees in industrial and engineering psychology from North Carolina State University.

Howard Parris, also in the Engineering and Operations Department, has been an EPRI program manager since January 1979. Before that he was with the Air Force Human Resources Laboratory in San Antonio, Texas, for 7 years. Earlier, Parris managed human factors engineering for Lockheed Georgia Co. for 7 years, following a 22-year military career in the Air Force, most of that time also in R&D. He earned MA and PhD degrees in industrial psychology at the University of Southern California and Ohio State University, respectively.

■

Bigger fuses take longer to act . . . until now. **Fault Protection for High-Current Distribution** (page 14) reviews the development of a new device that can work very fast to protect even the larger equipment on today's heavily loaded electric systems. Jenny Hopkinson, *Journal* feature writer, wrote the article with the technical aid of Joseph Porter, a project manager in EPRI's Washington, D.C., office.

Porter has been with the Electrical Systems Division since June 1978, managing R&D associated with several programs of the Transmission and Power Systems departments. He was previously with General Electric Co. for 30 years, becoming manager of the company's high-power laboratory for circuit components and subsequently heading the development and introduction of new 15-kV switchgear.

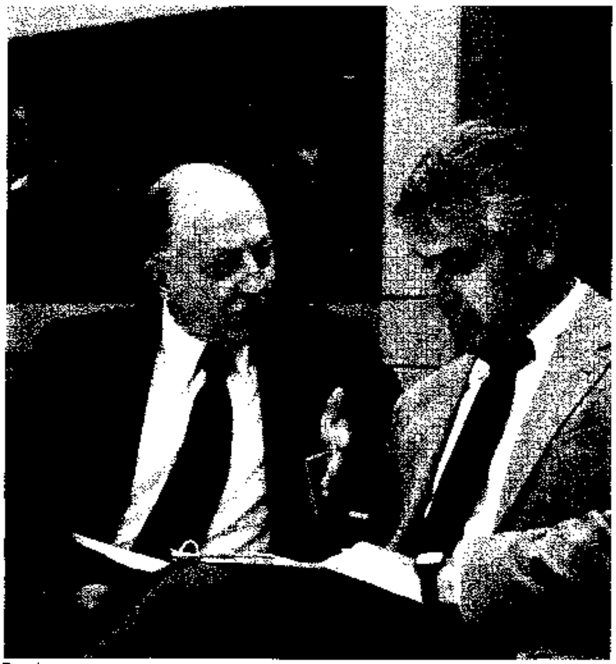
■

Collecting, storing, and distributing solar energy by the natural action of shape, materials, and exposures, passive solar homes easily show 20 percentage points of space heat savings when compared with the results of more conventional energy conservation measures. Science writer William Nesbit's article, **Evaluating Passive's Potential** (page 18), puts this finding into the broader context of a technology impact analysis managed by Gary Purcell of EPRI's Energy Management and Utilization Division.

Purcell has been associated with evaluations of solar heating and cooling since he joined the Institute in August 1977. Specializing in instrumentation for system control and measurement, he draws on the earlier experience of 14 years at Lockheed Missiles & Space Co., where he was a thermodynamics engineer for design, test, and analysis of aerospace temperature control systems. Purcell is a mechanical engineering graduate of Oklahoma State University.

■

Politics and the ministry are not traditional qualifications for public utility regulatory work. But they both figure in the background of the man presented in this month's profile, **Stanley York: Practicing the Public Interest** (page 24). Because York is also a member of EPRI's Advisory Council, Ralph Whitaker, *Journal* feature editor, sought him out for the interview on which this article is based.



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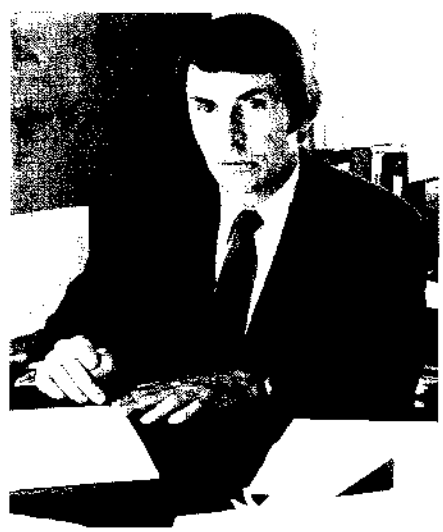

Purcell

Designing for Man: Advances in Control Room Operation

Alongside the boilers, pipes, valves, and turbines of all power plants there is a sophisticated piece of equipment that is indisputably essential to safe and economic power generation. This special component—the human being who operates and maintains the power plant—can affect power generation for better or worse, just as hardware can. Designers, engineers, and regulators have tried to accommodate the human being by such means as automating unusually complex plant systems or installing fail-safe automatic controls. But even these provisions may not have fully considered the human element.

The human factor

Control room operators at nuclear power plants face thousands of dials, meters, and indicator lights dispersed over large control boards. In some cases, components may not be arranged in clearly identifiable panels of related elements; sometimes related controls may not be near each other. Extensive alarm systems may sometimes confuse rather than alert the operator; communications with other parts of the plant may be difficult.

In the rest of the plant, maintenance personnel may have to squeeze past pipes and similar obstructions to make repairs while carrying equipment and tools, sometimes while wearing protective gear. They may encounter equip-

Power plants are made up of hardware, but they are operated and maintained by humans. Since TMI the role of human factors in safe and economic power generation has been more fully appreciated. Control board displays, alarm systems, procedures, and even the space allotted for making repairs are all under industry study.

ment tagged with indecipherable labels or no labels at all. They may be pressed to complete work under conditions of high temperatures and humidity and strict radiation stay-time limits.

The underlying reason for these operation and maintenance difficulties is lack of an integrated design approach that systematically includes human factors. Various system designers are each responsible for a part of overall plant design; each, in turn, affects control room and control board design and the maintainability of the plant. There are cases, particularly in older plants, where there has been inadequate communication between these groups, reducing the effectiveness of efforts to organize controls into an easily understood, workable format or to structure the plant for logical maintenance.

Many of these problems have been recognized for some time. The NRC's *Reactor Safety Study* (WASH-1400), for example, criticized design of controls and displays on operators' panels in nuclear plants as far back as 1974. A few human factors studies were commissioned by the utility industry before 1979, many of them inspired by human factors work by such organizations as the U.S. Air Force.

However, certain considerations inhibited human factors efforts in the utility industry. When plants began operation years after their initial design,

there was no established system for relaying the criticism of either nuclear or fossil fuel operation and maintenance personnel back to the original designers. So subsequent design efforts got scant real-world guidance. And because of the average 10-year lead time in building nuclear power plants, a whole generation of plants were designed without the potential benefits of extensive operating experience. Nuclear plants also had a large part of their design directed at incorporating increasing numbers of hardware features required by government safety regulations, so limited funding and time were left to optimize control room design and plant maintenance. Plant designs evolved, but all too often the human in the system was left to manage as best he could.

In 1979 the accident at Three Mile Island's Unit 2 precipitated a closer look at many aspects of nuclear power. Human factors deficiencies were identified among the causes of the accident. A misleading indicator, an important gage located behind a control panel, complicated alarms, and procedures inadequate for that particular situation all contributed to decision-making errors. This convinced the utility industry and NRC that the human component of the plant needed research just as much as the hardware did.

The industry responded with increased research into human factors, including a significant effort sponsored by EPRI; NRC furthered the push with a post-TMI action plan whose recommendations included human factors reviews of all reactor control rooms and increased provision for decision-making aids for operators. Nuclear power plants have been the principal focus of most human factors work in the utility industry because of their greater complexity and stringent safety criteria. But wherever humans worked, human factors problems turned up. Studies showed that fossil fuel plants presented opportunities for human error in such exacting operations as feeding fuel and combustion air into boilers. Costly maintenance and operation errors were discovered at many fossil fuel plants. Even dispatch control centers had a hard time keeping operators constantly apprised of thousands of power distribution details displayed on huge mapboards covering entire service areas.

Inside the control room

The painstaking self-examination began in the control rooms of nuclear power plants. Well before TMI, EPRI had commissioned a review of human factors in five representative nuclear power plant control rooms. The review turned up definite human factors shortcomings. Since TMI, human factors oversights have also been confirmed by the Kemeny, Rogovin, and other reports, as well as during NRC-recommended human factors reviews of control rooms. Although not all control rooms were troubled by these discrepancies, it was also not unusual for many human-engineering discrepancies to be identified in a single control room.

The types of human-engineering problems found by the five-plant EPRI review and by other industry reviews were varied. Control boards, for example, contained thousands of components. Many of the dials and switches were identical in appearance; many were not arranged into clearly identifiable clusters of related elements. Closely related controls and displays were sometimes separated. In general, the operator had to integrate scattered bits of data and systematically relate them to plant control. Color codes on control boards were not always consistently applied; labeling was sometimes a problem. (In some plants, operators used tape and handmade labeling to improvise their own control board improvements, delineating groups of controls and instruments or identifying functions.) Some meters were inadequately marked, difficult to interpret, or markedly above or below eye level; glare and reflections were reported. Sometimes there was a lack of meter coding to help the operator quickly differentiate between normal, marginal, and out-of-bounds readings.

The presence of these or similar discrepancies does not mean that the plants where they occur are dangerous to operate; it does mean that control room designs are not perfect. By correcting the discrepancies, safe and economic plant operation can be enhanced.

Since utilities became aware of these human-engineering problems, efforts have been made to correct them. Many of the human-engineering discrepancies in existing plants can be—and have been—improved by a relatively inexpensive paint-tape-and-label effort. Simple design modifications can often be made in plants still on the drawing board. Other shortcomings are more difficult and costly to correct, and they may involve adding, removing, or moving instruments in existing or design-stage plants.

Within EPRI's Nuclear Power Division, the Engineering and Operations Department under the direction of A. Rubio has launched a series of guidebooks that utilities, architect-engineers, and vendors can use to correct human factors discrepancies. The full range of aids now available to utilities for revising existing control rooms or designing new ones is cataloged by Program Manager Howard Parris. An anthropometric data base, assembled with help from the U.S. Air Force, provides design engineers with much-needed information on power plant personnel dimensions, such as reaching and viewing distances; another study offers general guidelines on methods for human factors control room design. More recently, a guide was published for enhancement of existing nuclear control rooms. This fall, a detailed design guide for new or modified plants will be available.

Another human factors study, focused not on nuclear plant control rooms but on dispatch control centers, is under way in EPRI's Electrical Systems Division. Human factors problems have been identified in these centers, and improved control centers are now being designed.

Equipped with these guides, the industry can refurbish its control rooms as needed. The new enhancement guide, for example, gives complete directions on methods (such as taping) to segregate related controls from other controls; better use of labels to identify controls is also detailed. Meter banding, which lets operators see at a glance whether a reading is normal or abnormal, is described. The guide covers all generic human factors areas of the control room.

More-recent studies spotlight specific human factors problem areas, such as alarm and communication systems. Alarm, or annunciator, systems consist not only of signal alarms and lights but also of controls for acknowledging, silencing, testing, and resetting the alarms. There are typically 1200–2000 individual alarms in a nuclear power plant control room. These systems are complex, and the hundreds of lights and alarms activated during emergencies may overload operators.

A computerized alarm-handling system called HALO (handling of alarms with logic) is being developed at the Organization for Economic Cooperation and Development, Halden Reactor Project, Norway. This system suppresses multiple signals about a process condition, showing only one alarm. EPRI's Nuclear Power Division is starting development of an improvement guide for alarm systems. With this guide, a plant can review its alarm system, deleting unnecessary alarms and adding needed ones, according to Project Manager John O'Brien.

Internal plant communication is another troublesome area from the human factors standpoint. An EPRI survey of selected control rooms concluded that existing communication systems in some nuclear power plants may not be adequate for certain critical demands made on them. Expanded communication requirements, staffing beyond original design, and lack of integration among the various communication systems have all compounded the problem.

The survey deduced that the control room has many communication requirements but not always enough communication channels: mainly, limited telephone and paging systems. Some systems may need improved maintenance; communication procedures may need to be followed more consistently. A standard lexicon could minimize the possibility of errors. O'Brien recently began a project to write guidelines for improved communication systems at nuclear power plants.

Not just equipment

Operation problems are not restricted to control room equipment. Procedures, for example, can be improved, and vigorous efforts are being made throughout the industry to upgrade them. One approach, job performance aids, is offered by EPRI. These aids, or JPAs, modeled after Department of Defense aids, detail specific jobs with the help of simple, step-by-step, extensively illustrated texts. The aids are much more specific than conventional procedures and are available for operation as well as maintenance procedures. Ten aids are now available, including initial loading and turbine startup.

Operator training is another human factors area being revamped. For example, post-TMI studies concluded that operators should be given frequent refresher courses covering unusual emergency situations. The Institute of Nuclear Power Operations (INPO), formed after TMI to establish standards of excellence in the management and operation of nuclear power plants, is charged with setting criteria for training programs and instructors. INPO now evaluates operating practices at nuclear plants regularly. Emergency preparedness and human aspects of plant design are evaluated as well. EPRI and INPO coordinate their work in this area.

Today, more training simulators are available than ever before—about 20, compared with fewer than 10 approximately five years ago. More are on order. A crew of three operators can be tested with training simulators. Each crew member has specific job responsibilities. An instructor initiates an event and observes crew response, but it is difficult to keep accurate track of responses, and errors might be overlooked. A few simulators record operator responses, but none analyze them. EPRI has developed a performance measurement system (PMS) that not only captures the operators' second-by-second responses, but also analyzes the data and supplies the instructor with a list of any errors made. O'Brien reports that a variation of the PMS might someday be used to provide on-the-job feedback to operators. In the future, there may also be a trend toward smaller, more flexible simulators, or part-task trainers, which can focus on a specific job area at a lower cost than a full simulator.

Better decision making

Human-engineering improvements are necessary in control rooms, but new techniques for information organization and processing can also be an effective way of helping operators make decisions, particularly during emergency situations when rapid problem diagnosis and quick action are required. The industry recognized this need before TMI and had begun to develop a disturbance analysis and surveillance system (DASS) through EPRI's Safety and Analysis Department, Nuclear Power Division. This computer model would alert operators to any unusual events within the plant. Work on DASS was proceeding at the time of TMI; since TMI, NRC has recommended that operator decision aids, especially computer-based aids, be incorporated into nuclear control rooms. EPRI continued to develop the longer-term DASS, but also began research into a more near-term option called a safety parameter display system (SPDS).

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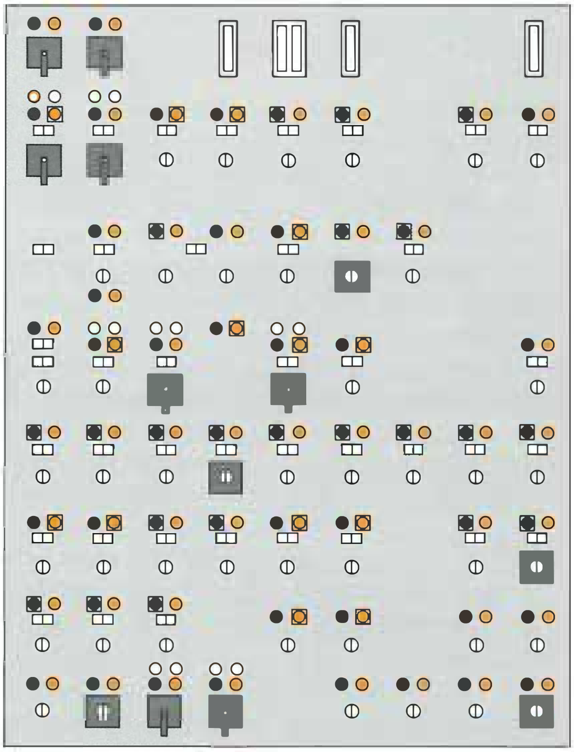

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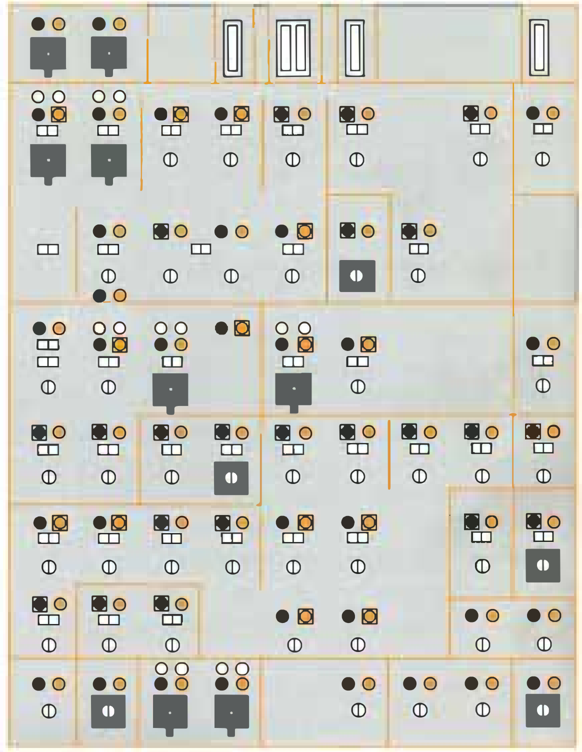

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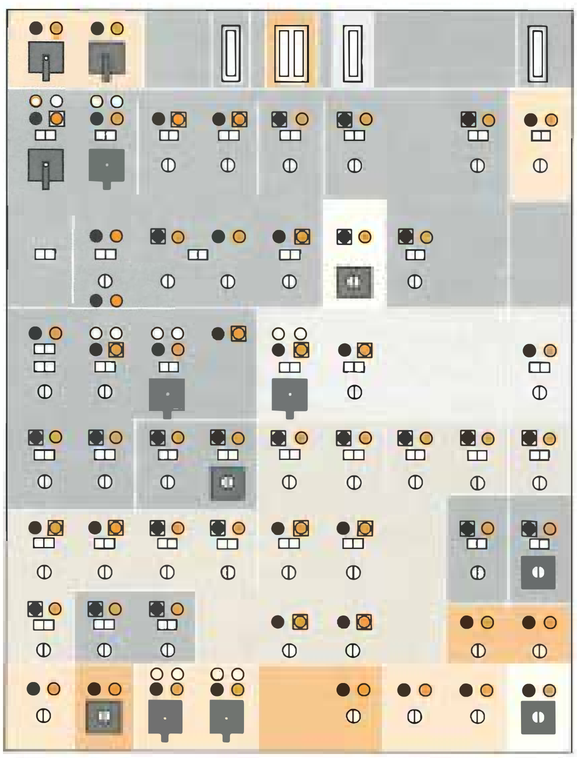
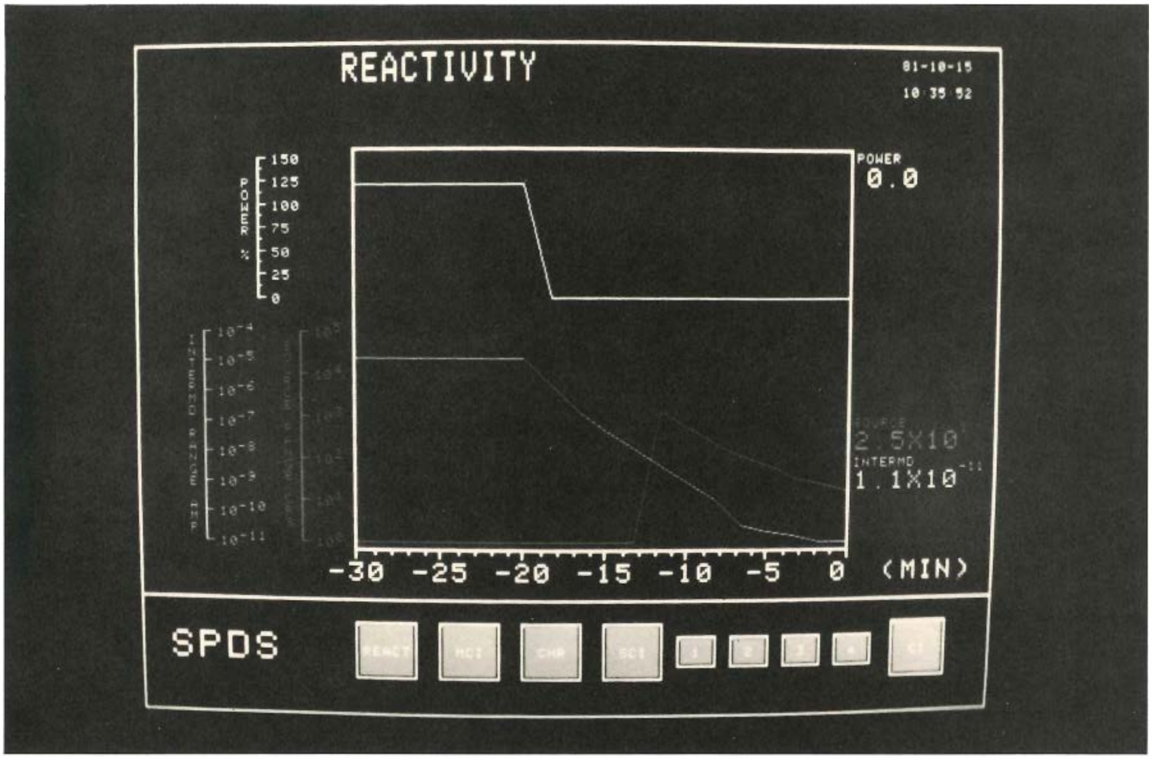


The Operator's Point of View

Nuclear power plant operators rely on thousands of dials, displays, meters, and indicator lights to keep informed of what is happening inside the plant. Based on that information, operators must then activate a wide range of switches, knobs, and levers to run the plant. The job can be made easier, sometimes with low-cost modifications. An unimproved control board, for example **(a),** may be potentially confusing because of the similarity of its components and the lack of order among them, but simple tape borders can be applied **(b)** to delineate different control functions; color backgrounds **(c)** can achieve the same effect.

In addition to enhancements of existing equipment, new operator aids can be added to the control room. Such aids, now under development, will keep operators apprised of plant status and will be particularly useful in emergencies when quick problem solving is required. Safety parameter display systems **(d)** present a few basic safety indications distilled from hundreds of plant information points that an operator needs to monitor. EPRI's disturbance analysis and surveillance system **(e)** goes still further; this advanced computer model summarizes all major safety and availability functions.

d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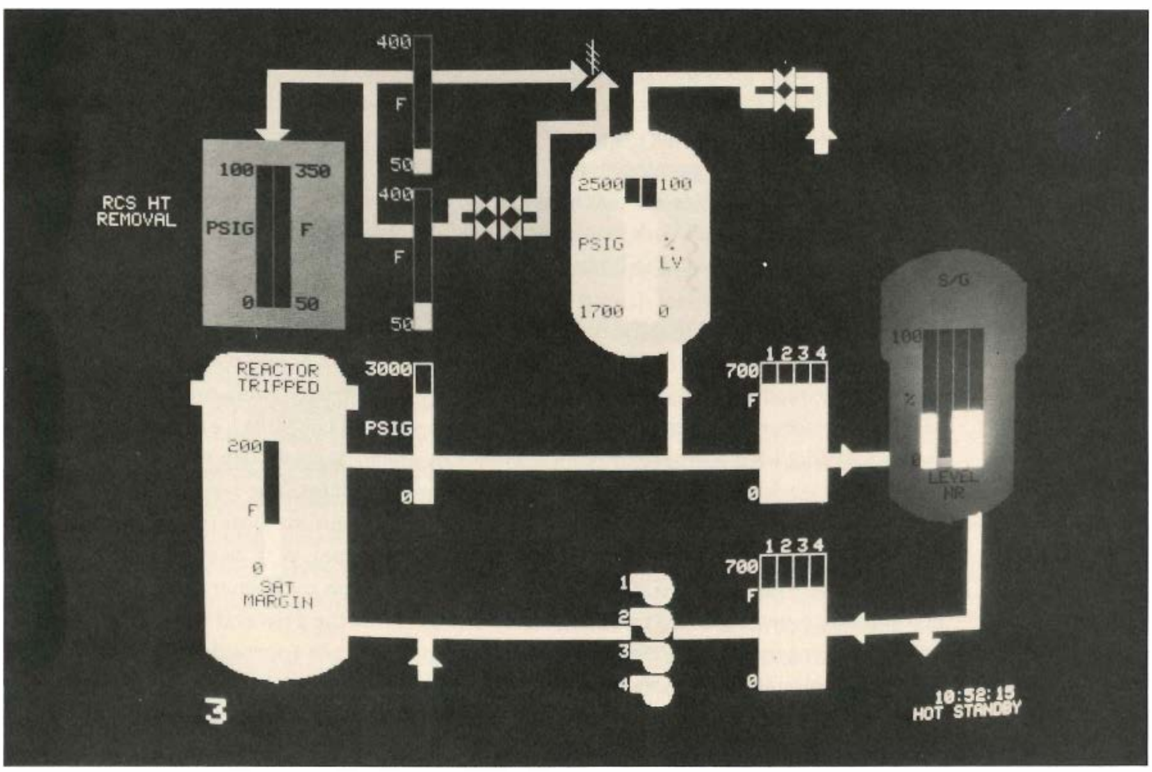
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HOT STANDBY

EPRI's Nuclear Safety Analysis Center (NSAC) conducts the latter work. Other SPDSs are being developed by utilities and vendors.

One SPDS recently tested by EPRI on a plant simulator is now being installed for field tests at an existing plant, according to NSAC Program Manager David Cain. This SPDS provides status reports on about 30 key safety parameters, an impressive distillation of the hundreds of parameters that an operator otherwise has to monitor. Five major safety areas are covered: reactivity, primary coolant inventory, secondary coolant inventory, core heat removal, and containment integrity. With an SPDS, the operator can spot trouble, access further information, and make a decision on the appropriate action to be taken.

SPDS is only an early step in the effective use of computers to help operators diagnose and solve plant problems. DASS takes SPDS further: instead of being limited to monitoring critical safety functions, DASS is a more complex conceptual model of major safety and availability functions. A limited DASS might be tested at a power plant early next year. DASS Program Manager Alexander Long and NSAC's Cain are working together to integrate their respective systems.

The development of SPDS, DASS, and other computerized operator aids reflects a trend toward the use of computers and CRT screens and away from the older hardware of mechanical displays and event recorders in control rooms. Yet the newer control rooms will merely be a different way of packaging existing information. The packaging must be well thought out, or problems comparable to those of conventional control rooms may be encountered.

Other new ways in which nuclear power plant operators are being helped perform their jobs are the addition of a shift technical adviser and an on-site technical support center at each plant. The technical adviser is stationed in the control room and backs up the regular operators in evaluating any problems that may arise. The technical support center, staffed by auxiliary operators and technicians during emergencies, is available to advise regular operators as needed.

On to maintenance

Although human factors reassessment began in control rooms, it does not end with plant operation. Power plant maintenance needs work, too, as an EPRI overview study on maintainability conceded after examining a sample of five nuclear and four fossil fuel plants. Special concern for power plant maintainability is necessary not only for the safety of maintenance personnel but also for plant integrity and availability.

According to the report, one of the biggest difficulties maintenance personnel faced was access to the equipment they service. Some equipment and components were packed so closely that maintenance personnel could not easily maneuver themselves and their tools into working positions. Sometimes components were placed so that they were difficult to reach or visually inspect. Frequently, special access provisions were inadequate; repairmen had to clamber over equipment or perch on it, possibly damaging it. Work platforms and ladders sometimes had to be built to avoid this problem.

The report also noted that the maintenance environment in plants, particularly nuclear plants, was hostile in many respects. Personnel must be protected from radiation, high temperatures, steam leaks, and high noise. Yet some components were in highly radioactive areas where stay-time was strictly limited and where design did not easily accommodate personnel equipped with protective garments, air bottles, and face masks. Maintenance personnel at fossil fuel plants were burdened with the same high temperatures, leaks, and noise; they also had coal dust and fly ash to contend with. Many operating plants are 20 or even 30 years old and do not incorporate modern design improvements.

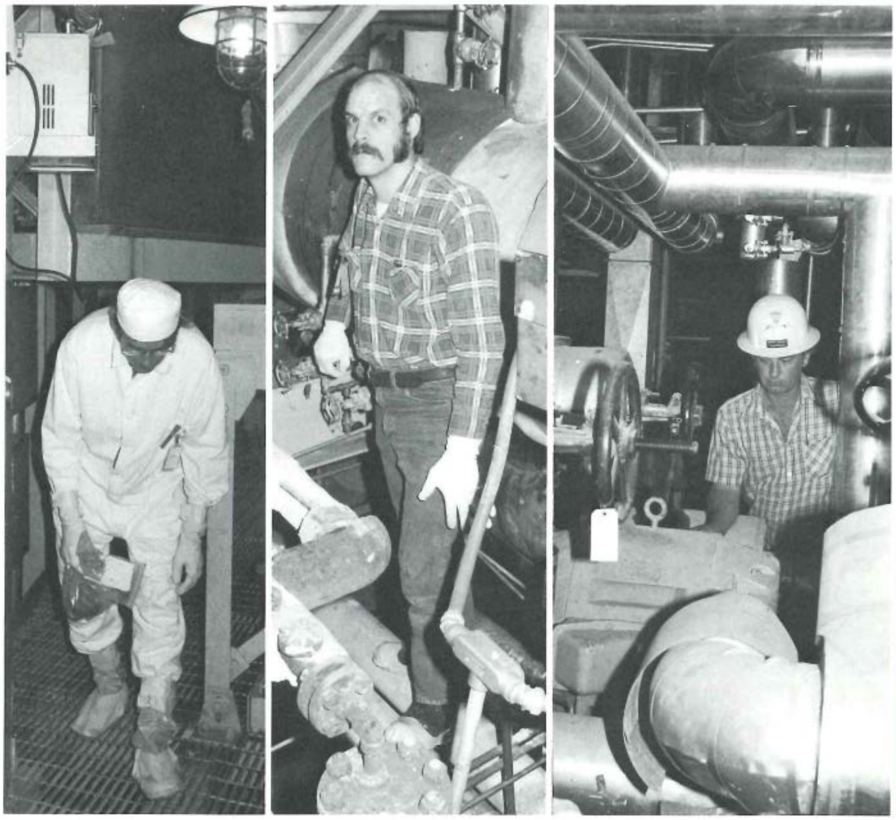
Many complaints centered on provisions for the movement of personnel and machinery. Sometimes plants offered passenger elevators where heavy-duty cargo elevators would have been more appropriate. Elevators frequently broke down under rigorous plant conditions. Additional crane coverage was also found to be needed in many cases. More widespread availability of pad-eyes for hoisting large pieces of equipment was indicated. Where a facility was not designed to allow forklifts or other transportation aids, crews had to move 600-pound barrels or 300-pound pumps themselves.

Effective labeling and coding techniques were often underused in power plants. A common problem with labels was legibility; dirt, wear, corrosion, and dim lighting could also make identification of components difficult. The wrong units were sometimes disassembled for repair. Multiunit plants are especially susceptible to maintenance errors of this type.

Efforts are under way to improve the maintenance climate at power plants. EPRI's anthropometric data base has been distributed to plant designers, and many are using it. This may help avert such problems as tight repair squeezes and out-of-sight meters. In direct response to utility requests, EPRI has developed a guide for assessing and enhancing nuclear power plant maintainability. "It's strictly a self-improvement, do-it-yourself checklist," explains Parris; it can replace a costly trip to a human factors consultant. The recently completed guide outlines information-gathering techniques, such as structured interviews with maintenance personnel, and presents the pros and cons of various maintenance approaches. EPRI's step-by-step job performance aids also include such maintenance tasks as repairing respirators, maintaining circuit breakers, and replacing pump seals. Work has recently begun on development and testing of a preventive maintenance model. This model, when provided with plant-specific data, can help a utility choose a cost-effective preventive maintenance program.

To make maintenance easier, EPRI has developed a cool suit—16 pounds of water-filled compartments built into a two-piece repair suit that can be frozen to keep body temperatures at acceptable levels for up to two hours in high-heat areas of the plant. The suit can also be used in excessively warm areas of fossil fuel plants. An ergonomics guide, which examines alternative solutions to heat stress (such as rest cycles and worker screening), as well as other human problems, is also being developed. Meanwhile, the Coal Combustion Systems Division is conducting a study on boiler operation and maintenance in fossil fuel plants. Results from previous studies confirmed that most human errors in that area occur in maintenance, not operation, activities. Significant job activities are now being identified so that human factors improvements can be recommended.

Power plant maintainability is another area where human factors apply. One of the biggest difficulties maintenance personnel may encounter is access to the equipment they service.



Proceed with care

Human factors are getting increased attention and action, but because so much more research is required and so many improvements are still to be made, the effort must proceed carefully and systematically. Because few new nuclear plants are currently being built, many of the improvements will be retrofits in existing plants. "We're talking about changes in the equipment and procedures that are in use," emphasizes Nuclear Power Division Director John Taylor. "If these changes aren't done in an orderly way, they can create the potential for trouble in plants that are now running."

The problem of too quickly instituting changes has a high priority within the industry. When NRC recently surveyed nuclear power plant staffs about the potential safety consequences of NRC regulatory activities since TMI, staffers replied that the pace and nature of regulatory action had indeed created a potential safety concern of unknown dimensions.

To avoid precisely this problem, EPRI's human factors work emphasizes thorough validation of new techniques through simulators and mockups and enlists the help of real operators and INPO. "It's a very special challenge," concludes Taylor. But the rewards are wonderfully tangible. Just as all the mechanical parts of the plant can be synchronized to work together, so the human operators and maintainers of plants can work in synchrony with the plant. The reward is safer, more efficient power production.

This article was written by Nadine Lihach. Technical background information was provided by David Cain, Walter Loewenstein, Alexander Long, John O'Brien, Howard Parris, A. David Rossin, and A. Rubio, Nuclear Power Division.

Further reading

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Summary and Evaluation of Scoping and Feasibility Studies for Disturbance Analysis and Surveillance Systems (DASS). Topical report for RP891-3, prepared by EPRI for DASS Technical Advisory Group, December 1980. NP-1684.

Evaluation of Safety Parameter Display Concepts. Final report for RP891-5, prepared by Westinghouse Electric Corp., February 1982. NP-2239, Vol. 1.

Whenever a short circuit strikes an electrical system, the current increases rapidly and surges from the generating source or transformer along the line in rather the same way that water gushes from a breached dam. This wave of current, if uncontrolled, can exceed the thermal and mechanical capability of electrical devices and severely damage lines and equipment, as well as jeopardize power supply to utility customers.

All types of electrical systems are vulnerable to this problem, which can result from a number of causes, such as a breakdown in conductor insulation or the overheating of a transformer winding. But the risk of fault currents increases with the size, or capacity, of the electrical source—the transformer. Large urban areas like New York City and giant plant complexes that have their own distribution systems often have loads that require huge substations, drawing much more than 200 A.

The increasing risk of high fault currents is also a consequence of the present move toward uprating electrical systems in general. The rise in continuous current is often a result of extra power sources being added to a system, both to supply growing loads and to maintain system reliability.

Circuit safeguards

Electrical circuits need fast-working devices to protect them from abnormal current surges. Traditionally, the silver sand current-limiting fuse has filled this role for normal continuous current up to 200 A. This device works swiftly; a silver fuse melts in an enclosure of sand, interrupting the fault current within the first half-cycle of alternating current (ac), that is, in less than 8 ms. However, the higher the continuous current carried by a line, the larger the fuse must be in order not to melt under the heat of normal current. Unfortunately, the fuse's greater size means that it also takes longer to melt in the event of a fault current, giving that fault current time to rise to a higher level. For this reason, the fuse is ineffective as a circuit protector when it has to carry continuous current over 200 A.

In most cases, circuits rated above 200 A and up to 3000 A are safeguarded by circuit breakers, which arrest fault current with current-interrupting devices that use oil, air, vacuum, or SF_6 gas. However, in contrast to the current-limiting fuse, circuit breakers are relatively slow to take effect—between three and five ac cycles (at 16 ms per cycle) to interrupt current. During this period, fault current can inflict severe thermal and mechanical stresses on electrical apparatus. For instance, the heat at peak levels can burn overhead lines or underground cables, while electrodynamic forces can deform bus work and switches or expand the coils of transformers and reactors.

The requirement, then, is to devise a circuit protector that can carry high normal current day in, day out—up to, say, 2000 A—yet still limit the magnitude and duration of fault current to less than 15,000 A and well within the first ac cycle. Phoenix Electric Corp. and EPRI came up with an answer: a new concept combining the "high-current-carrying capabilities of the circuit breaker and the extra-protective characteristics of the current-limiting fuse," as EPRI Project Manager Joseph Porter describes it. The result is the CLP, a compact 28×7-in cylinder of fiberglass that contains a copper bar conductor in parallel with a conventional silver sand current-limiting fuse. Being relatively lightweight, the CLP can be positioned on a pole, a wall, or almost any convenient structure on a line. It has low power losses (waste heat), comparable to a 20–30-W light bulb, so it is more economical than a common alternative, the current-limiting feeder reactor, which has losses between 3000 and 4000 W.

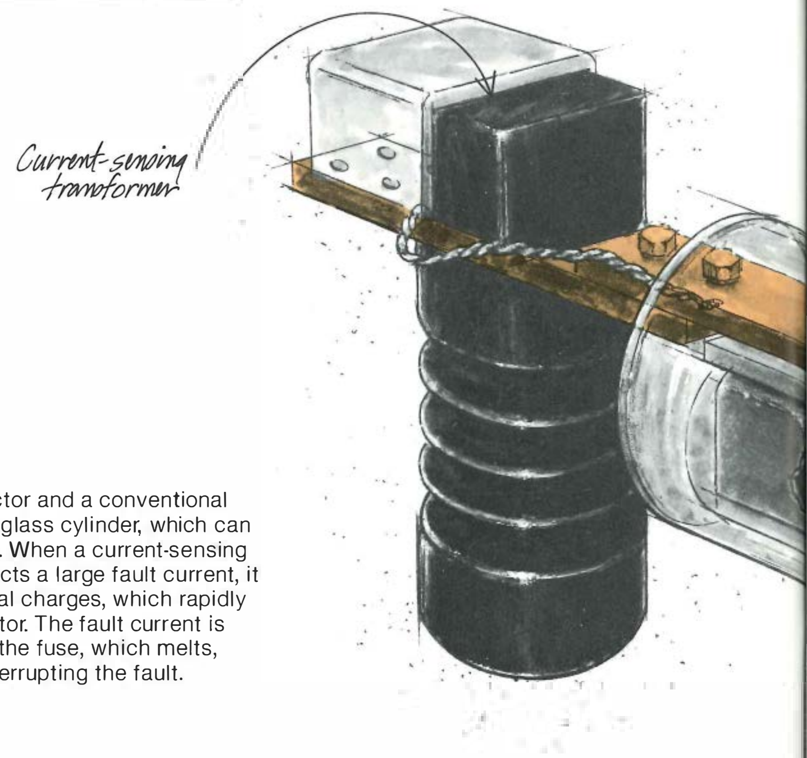
CLP function

In normal operation, current predominantly runs through the CLP's copper bar conductor. But in the event of a fault current, a sensor-and-trigger mechanism fires a series of chemical charges, which cut special, thin sections of the copper conductor in several places (for example, four cuts on a 15-kV line; fewer at lower voltages). The pressure of the gases given off by the charges bends these severed sections upward, creating gaps and diverting current into the parallel fuse. The fuse then melts rapidly, generating an opposing voltage higher than the circuit voltage, which forces the current to zero even before the normal peak of fault current can be reached. (The deceleration effect of opposing voltage can be compared to that of reversing an engine.) This dual operation involving the conductor and the fuse causes the rapid and safe interruption of the fault current.

The CLP can be set up to activate a device at the utility when the circuit is interrupted, signaling the need for the replacement of the CLP, a task that takes a few hours.

The CLP's triggering sensor, a doughnut-shaped element surrounding the copper conductor, consists of a current transformer and a comparator that constantly measures the current level in the circuit and compares it with a set point limit in much the same way as a thermostat checks air temperature. At the instant the current exceeds the preset limit, say 10 kA, the chemical charges are activated and the fault current is controlled. A balance must be found in setting the sensor at current levels low enough to protect other apparatus downstream, yet high enough to avoid unnecessary operations. The standard devices already on the line should be able to cope with most fault currents, which are those at intermediate level.

In addition to the CLP's ability to withstand high continuous current, it has another advantage over the ordinary fuse that is related to the way alternating current is transmitted. The wavelike flow of ac is inherently uneven, so it is generated in three parts or phases, each phase displaced in time to produce a smoother power supply. The CLP can be triggered



How the CLP works

The CLP houses a hefty copper conductor and a conventional silver sand fuse inside a 28 × 7-in fiberglass cylinder, which can be mounted almost anywhere on a line. When a current-sensing transformer connected to the CLP detects a large fault current, it triggers the firing of a series of chemical charges, which rapidly cut special thin sections of the conductor. The fault current is immediately limited and transferred to the fuse, which melts, dissipating the current's energy and interrupting the fault.

to interrupt all three phases of a circuit, while a fuse breaks only the one or two phases that have a fault. Removal of only one or two phases provides a rough power supply, and large motors that are designed to run on three-phase current can overheat and become damaged when doing the same workload on reduced power. The CLP, by entirely interrupting all three phases, helps avoid such damage.

In instances where old fuses function spuriously on circuits that have been uprated to carry current close to the fuse's protective threshold, CLPs can be installed to replace these fuses, as they can better withstand high continuous current. Whereas fuses are designed to melt at one particular current level, determined by the size of the fuse, the protective threshold of the CLP can be adjusted at any time, making it less likely to become obsolete.

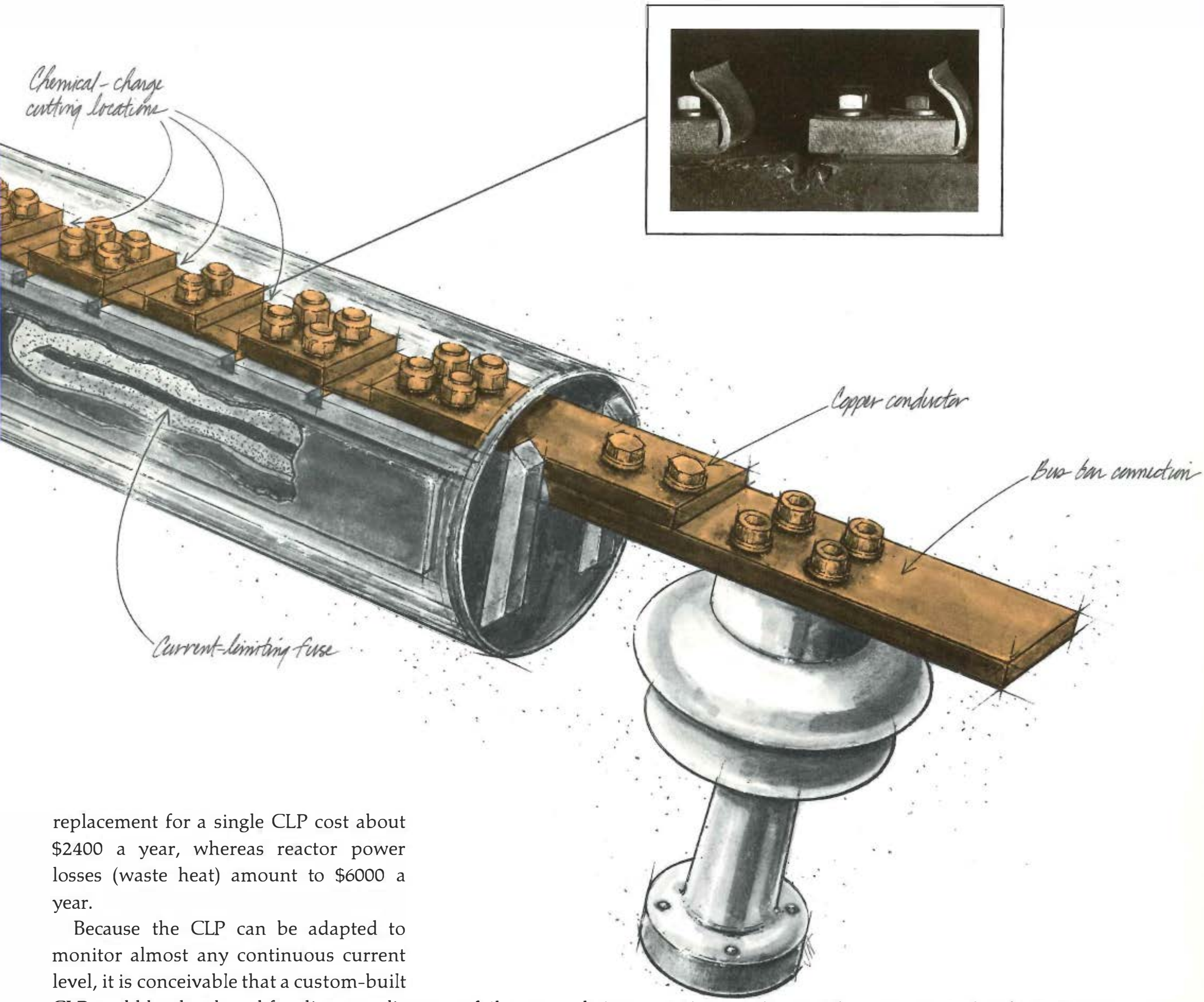
Where existing circuit breakers give insufficient protection from the growing risk of fault current, the CLP can be installed to precede them, indefinitely postponing costly purchase and installation of new, larger breakers. The relatively low cost of a distribution-class CLP will allow its widespread application in branch circuits, where its guarantee of keeping fault currents to low levels will avoid the need for designing and manufacturing heftier, more-expensive switchgear and apparatus.

Tests and savings

Full short-circuit tests of the CLP have been successfully carried out on 4-kV to 15-kV circuits (distribution class) at the General Electric Co.'s high-power laboratory in Philadelphia. Prospective short-circuit currents of 40,000 A rms (root mean square, or average continuous current value of energy in one cycle, as opposed to peak energy) were limited to less than 15,000 A (peak).

Boston Edison Co. and Consolidated Edison Co. have both been instrumental in the development of the CLP. Boston Edison installed one CLP for in-service testing at its Woburn substation in Massachusetts, and Consolidated Edison conducted field trials on Staten Island with a CLP installed on overhead lines. Consolidated Edison expects to add 10 CLPs a year to its system in 1983 and 1984.

Because the capital cost of a CLP is only about 10% of the cost of the alternative, the current-limiting feeder reactor, Consolidated Edison will benefit from the cost differential: $15,000 to install a CLP against $150,000 to install a reactor. Savings are also evident when operation and maintenance of the two devices are compared: service and fuse



replacement for a single CLP cost about \$2400 a year, whereas reactor power losses (waste heat) amount to \$6000 a year.

Because the CLP can be adapted to monitor almost any continuous current level, it is conceivable that a custom-built CLP could be developed for direct application on a generator bus. The very high operating speed (in the present model, 25 μs from sensing to cutting the conductor, 75 μs for the fault current to transfer to the fuse, and another 100 μs to melt the fuse) would ensure complete security of equipment connected directly to the generator terminals.

Phoenix Electric is working on a project with DOE to develop fault current protection of large auxiliary power transformers connected directly to generator buses. As Thomas F. Clark, president of Phoenix Electric, points out, "Transformer failures result in expensive repairs and long outages. Our objective is to develop a device similar to a CLP that will protect equipment connected to the generator against fault currents of several hundred thousand amps."

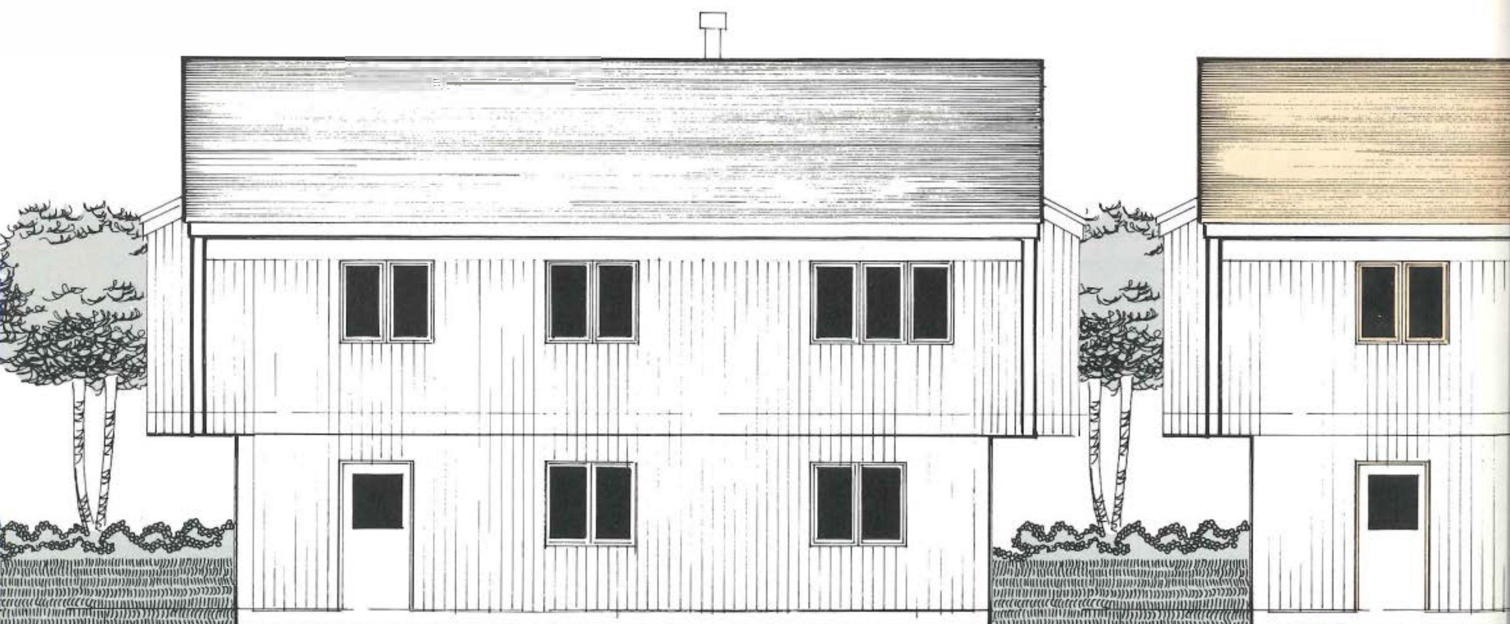
At the other end of the scale is the concept of a small, 4×5-in CLP, which Hussein ElBadaly, manager of electrical power systems research at Consolidated Edison, is discussing with Phoenix Electric. This distribution-class CLP would protect a 480-V circuit and would have to be small enough to fit in the same space as the 5000-A fuse it would replace.

The new principle of joining two apparent electrical opposites—a solid conductor and a fuse—is a paradox, yet thoroughly practical. Further, different sizes of the generic device may answer a wide range of fault current problems. Porter comments, "When used in applications that call for its unique characteristics, the CLP can provide effective system protection and also reduce distribution system capital costs and losses." ■

This article was written by Jenny Hopkinson. Technical background information was provided by Joseph Porter, Washington Office.

Evaluating Passive's Potential

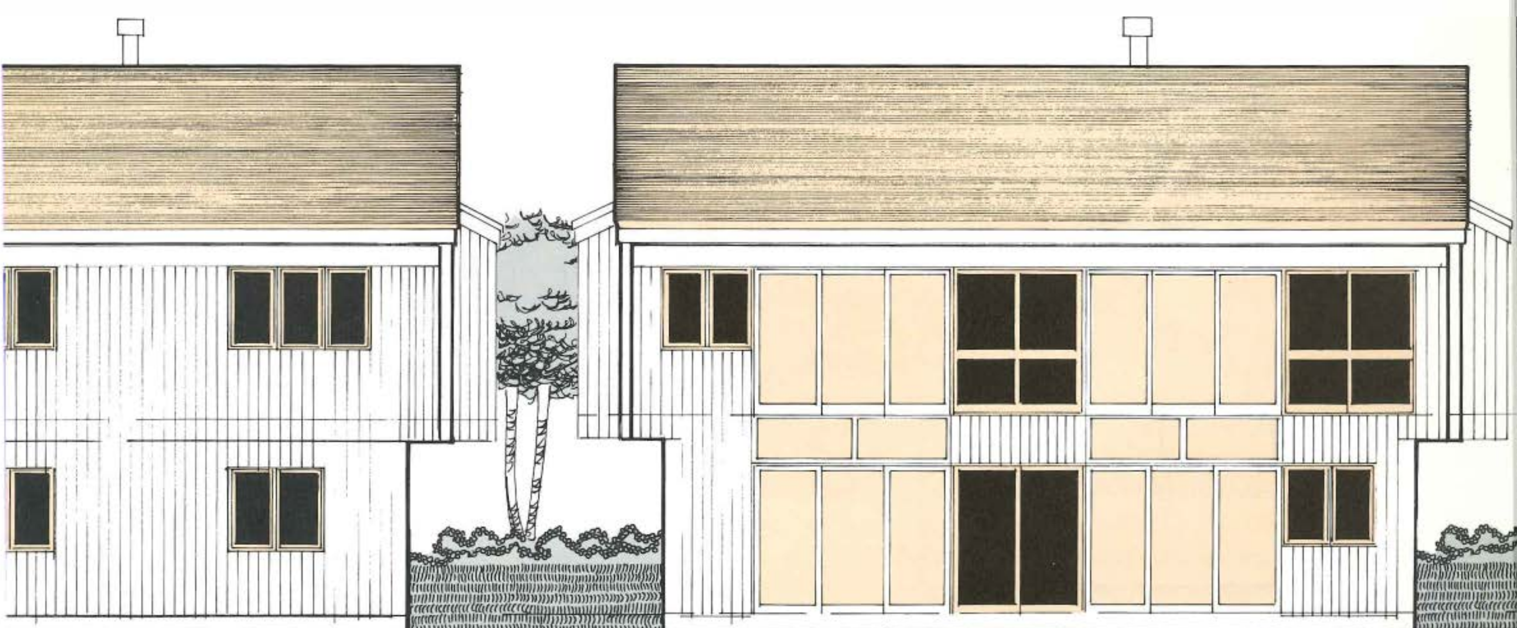
A flexible computer program compares the costs and thermal performance of passive solar homes with a conventional house and a well-insulated energy conservation home. Several utilities are now using the model to explore the potential impact of passive solar design in their service areas.



Conventional home

Interest in passive solar has increased significantly in the United States in recent years as one response to higher energy prices and the widespread popularity of virtually all solar technologies. Yet although a large number of new homes and other buildings incorporating passive solar design have been constructed, little work of a rigorous nature has been done to determine the effect these buildings have on electric utilities and the economic benefits, if any, they might offer utility customers in terms of energy savings.

To fill this gap, EPRI—in conjunction with JBF Scientific Corp.—has produced a computer methodology that simulates and compares the relative thermal performance of passive solar homes with a conventional home having limited insulation and with a very well insulated energy conservation home. The methodology then aggregates these results to assess homeowner energy use and costs and to predict the economic impact large numbers of each type of home would

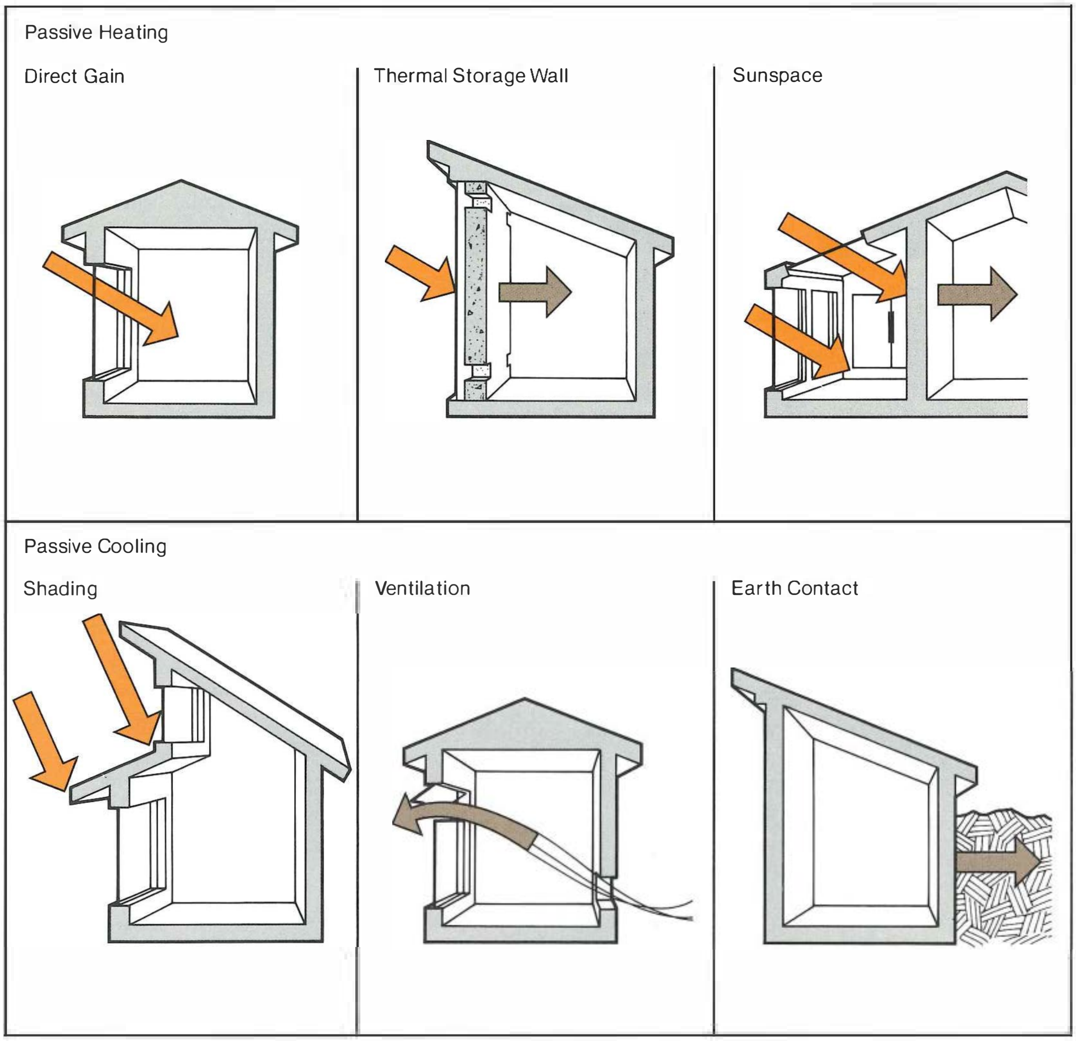


Energy conservation home

Passive solar home

Options for Passive

Passive solar systems rely on structural design rather than mechanical means to manipulate the sun's energy for heating or cooling. For heating, large windows or glass doors admit the sun for direct gain of heat on interior surfaces. Concepts that use storage walls and sunspace, on the other hand, are based on indirect gain, as when a wall heated by direct sunlight radiates that heat into the house interior. Passive cooling techniques, which have generally been less effective than passive heating, work by avoiding a house's direct gain of heat or by moving the heat from the indoors to the outdoors. Avoiding direct gain essentially amounts to shading—eaves with carefully calculated overhangs shade windows from the high summer sun. There are two basic ways to move heat to the outdoors. One, ventilation, involves the removal of heat by a stream of cooler outside air. The other, earth contact, involves heat loss to a cooler earth mass built up on an outside wall. Benefits of these heating and cooling techniques are largely additive, so a combination of options is normally used in the design of passive solar houses.



have on a given utility in terms of changes in kWh use, system load, fuel costs, and generation reliability.

"One seldom thinks that individual homes can influence a utility system, but it's true," says EPRI Project Manager Gary Purcell. "If a large number of one type of building is constructed within a utility's service area, this would certainly affect the utility."

In addition to modeling housing types, the computer program has the capability of simulating and comparing the performance of alternative and advanced electric heating and cooling systems. These include unitary and central air conditioning, central fans, evaporative coolers, heat pumps, resistance heating strips, and their controls. "We believe this broad base and flexibility to look at a range of single-family housing effects on utilities is a real strength of the program," comments Purcell. "In addition to gauging the impact of passive solar building design on a system, we can separately predict the effect of specific energy conservation measures, for example, or of heat pumps, or of evaporative coolers versus central air conditioning."

With this information, utilities can judge the extent of these heating and cooling alternatives, and advanced building designs could be employed within their service areas to help ease capacity and energy shortages. In turn, they can identify and quantify potential incentives to use in influencing home builders and homeowners to select the alternative that will provide the most efficient use of energy.

The program has already been tested by using utility data and was recently given to three utilities for independent assessment. It is scheduled to be introduced more broadly later this year.

Although tentative at this point, findings do indicate that passive solar buildings can offer potentially significant savings to both utilities and their customers in some areas of the country. "As might be expected," Purcell says, "the passive solar and the energy conservation houses consistently outperform the conventional house. Beyond this, the passive home seems to show the lowest life-cycle energy cost in areas where a heating load dominates and where there is an adequate amount of sunshine. This would include portions of the West, the Southwest, and many areas in the North."

Passive solar defined

Passive solar systems are those that collect, store, and distribute the sun's energy by natural, nonmechanical means. As such, they are based more on design than on technology and are easier to adapt in new construction than in retrofit application.

Key passive solar design elements include proper building orientation, large areas of south-facing windows, and building construction with heat-storing materials, such as concrete, brick, adobe, and water. Nearly everywhere in the United States, south-facing windows admit more heat than they lose; once brought into a house this heat can be trapped and held for use in cooler hours of the day.

Energy conservation measures are also integral to effective passive solar design. "You can't have a passive home without having a conservation home," explains Mark Schiff, a partner in the architectural firm of Edward Mazria & Associates, Inc., in Albuquerque, New Mexico. "It's an additive process. From a conventional home you go to a conservation home and then to a passive home."

Among an array of passive solar design options, direct gain, indirect gain, and isolated gain (or sunspace) are the primary heating concepts, and ventilation, ground contact, night radiation, and shading are the primary cooling concepts. These elements must be finely matched to climate and site. If they are not, systems can become costly in relation to the improved comfort and energy savings they offer. Quantifying this trade-off is one aspect of the EPRI program.

Because of resource and thermodynamic constraints, passive cooling is difficult to achieve, especially in areas of high humidity. Passive heating, on the other hand, is better understood and more widely practiced, with the direct-gain option—the simplest and least expensive—the one most commonly used.

In terms of potential for energy savings, passive solar heating can contribute 20% or more toward meeting the heating requirements of a building. Thus, while conservation can reduce the amount of energy used for heating in conventional homes by 50–60%, it is estimated that passive solar design can increase this to 80% in the Northeast and up to 90% in areas of the Southwest and West.

Cost for this added increment of energy savings varies appreciably because of the climate- and site-specific nature of passive systems and the wide variety of design options. However, a rough average would be approximately $4 a square foot of building floor area, or about 7–10% of the purchase price of a new home.

The EPRI program

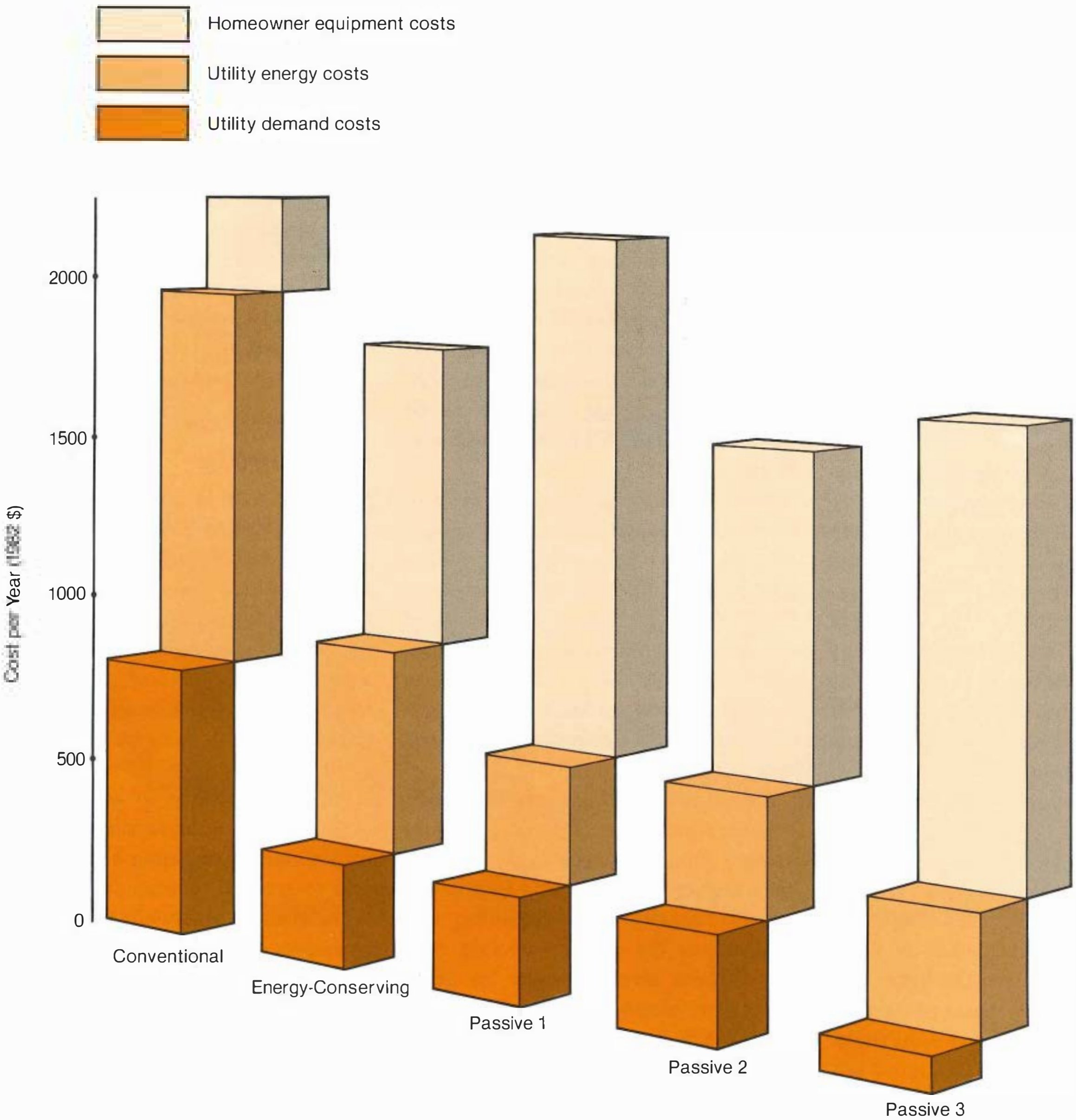
EPRI's program to assess passive solar's impact on utilities began with an analysis of heating and cooling degree-days, solar radiation, cloud cover, temperature, and humidity patterns throughout the country. Seven distinct climatological regions were defined in this analysis, and interested utilities within each were subsequently asked to participate in the program.

As a further step to add specificity to the work, an analysis site was selected within each participating utility's service area to serve as a location for the conceptual houses to be modeled in the computer program.

Participating utilities and conceptual sites included Boston Edison Co. at Boston; Pennsylvania Power & Light Co. at Harrisburg; Alabama Power Co. at Montgomery; Public Service Co. of New Mexico at Albuquerque; Salt River Project at Phoenix, Arizona; Pacific Gas and Electric Co. at Fresno, California; and

Comparing the Costs

A homeowner's yearly costs for heating and cooling are generally dependent on two factors, costs of equipment built into the house during construction (broken into yearly increments for the lifetime of the house) and costs paid yearly to the utility for service. The utility costs are based on energy costs (fuel) and demand costs (utility equipment plus operation and maintenance). A comparison of annual heating and cooling costs for five houses on Public Service Co. of New Mexico's system demonstrates how an initial larger investment in energy-saving options can be of significant long-term benefit to the homeowner—the conservation house and all three passive designs show lower life-cycle costs than the conventional design. Although this outcome is generally the rule, the magnitude of the benefit is highly site-specific, and figures will vary, depending on the passive options used. In the New Mexico examples, Passive 1 employs direct gain and a thermal storage wall for heating and natural ventilation for cooling; Passive 2, which shows the lowest cost, uses direct gain and mechanical ventilation; Passive 3 incorporates direct gain, a thermal storage wall, and evaporative cooling.



Pacific Power & Light Co. at Medford, Oregon, and Casper, Wyoming.

As a next step in developing program methodology, Mazria in Albuquerque and Massdesign Planners and Architects, Inc., in Boston were retained as architectural consultants to design reference building structures for each region that would be representative of mass-market homes likely to be built there through 1995. Mazria designed for the western locations, and Massdesign, the eastern locations. In addition, before beginning the designs, each firm performed market analyses within its assigned areas to establish local building trends and consumer preferences and to select the most representative building types.

Following review by a panel made up primarily of representatives of participating utilities, these designs were computer modeled as four different types of homes: the conventional home with limited insulation; the very well insulated energy conservation home; and two passive solar homes, one a basic, direct-gain design and the other a more aggressive design—that is, one incorporating supplemental thermal storage capability.

"We and the other participating utilities provided projections of our load growth and generation mix and of the number, size, and type of houses we expected to be built in our areas over about the next 15 years," explains Michael Lechner of Public Service Co. of New Mexico. "This included information on the type of heating these houses would use and how many air conditioners, heat pumps, and evaporative coolers we expected. In essence, we gave EPRI some baseline conditions to project the effect on our systems of all the houses we expect will be built over these coming years."

Program results

Passive solar impact assessments were performed for the four conceptual houses in Montgomery (Alabama Power Co.), Fresno (Pacific Gas and Electric Co.), Harrisburg (Pennsylvania Power & Light Co.), and Albuquerque (Public Service Co. of New Mexico). Montgomery and Fresno are cooling-load-dominated sites, and Harrisburg and Albuquerque are heating-load-dominated sites.

The energy conservation and passive solar homes significantly outperformed the conventional home at each of the four sites and in each of the four comparison areas: kWh use, system load, fuel costs, and generation reliability. Looked at separately, the best passive solar house was seen to perform incrementally better than the energy conservation house on the heating-load-dominated systems. On the cooling-load-dominated systems, the best passive house performed roughly equivalent to the energy conservation house.

In addition, at both heating- and cooling-load-dominated sites, passive solar reduced heating loads but increased cooling loads. At the heating-load-dominated sites this increase in the cooling load was not sufficient to cancel savings realized in heating. At the cooling-load-dominated sites it was, but only by a small margin.

An important mitigating factor in these comparisons is the present poor outlook for any appreciable amount of new home construction in the near future. As a consequence, passive solar's primary impact near term may be only on the individual home or subdivision level.

The computer model also projected a comfort index in terms of room temperature, humidity, and wall temperature to contrast the energy-conserving house and the passive solar houses with each other and with the conventional option. In this, the conventional home proved the least comfortable, while the passive home was seen to be roughly equivalent to the energy conservation home in the summer and slightly more comfortable in the winter. Life-cycle costs for both utilities and homeowners were also compared, with passive solar emerging as the preferred design on heating-load-dominated systems in regions with adequate sunshine. But again, this finding was extremely climate- and utility-specific.

"Our results clearly indicate that in some locations of the country, passive design should be a preferred option," affirms EPRI contractor Peter F. DeDuck of JBF Scientific. "But the detailed conclusions are extremely climate- and utility-specific, and in this regard, the benefits of passive designs vary considerably."

The next step

As the next step in program development, both the methodology and the model have been given to Kansas City Power & Light Co., Pacific Gas and Electric Co., and Carolina Power & Light Co. for their independent assessment on an experimental basis. Later this year, follow-up will be conducted to understand how the program was used, how useful it was, and where improvement is needed.

Beyond this, introduction of these tools to all EPRI member utilities is scheduled for later this year at two workshops, one to be held in the East and one in the West.

"An important bottom-line aspect of this study is that by using this methodology, utilities will be able to come up with some answers that are not intuitively obvious," comments Purcell. "It can be used to look at a number of heating and cooling aspects of the residential housing sector and to analyze this sector from a number of different points of view. In this manner, it could well prove a powerful predictive tool in determining how a changing housing stock may impact a given utility at a given point in time." ■

This article was written by William Nesbit, science writer. Technical background information was provided by Gary Purcell, Energy Management and Utilization Division.

Stanley York: Practicing the Public Interest

Sitting at the long, shiny table, Stanley York is at ease. The board room of Milwaukee's Good Samaritan Medical Center is a familiar setting. York has been a hospital board member for 11 years, and the quarterly board meeting will begin in just two hours. But for now he is considering his newer role as a member of EPRI's Advisory Council. Asked why he accepted it nearly three years ago, he replies, "In 1979 I had also just been appointed chairman of Wisconsin's Public Service Commission [PSC]. Research and development is an issue in rate cases—a formal question in our proceedings— and we need to understand whether or not it is legitimate for utility ratepayers to pick up the tab for R&D. I thought serving on the EPRI Council would be a good way of getting that information."

Today, York still holds the PSC post as his full-time job, and together with the other 24 members of the Council, he is working to strengthen their advice to EPRI's Board of Directors. The timing is right because events outside the electric utility industry are reshaping the industry's role and calling for new approaches (often involving R&D) to many of its tasks. It can't be said that York is the only person for the time and place, but his background, much of it far from traditional for regulatory work, is both a powerful motivator and a source of useful skills.

Practicing what he preached

York is best characterized as a public servant, although he has not played consistently visible roles. During the 1960s he was twice elected to two-year terms as a Republican assemblyman in the Wisconsin legislature. In the 1970s, before coming to the PSC, he held three appointive state offices under both Republican and Democratic governors. In between times, he was executive director of the state Republican party for three years and executive director of the Wisconsin Association of Homes for the Aging for four years.

But something else colors York's actions wherever he works. After graduating from Beloit College in 1953, he went on to Andover Newton Theological School; and for 13 years before 1970, he was a Congregational minister (United Church of Christ). His transition (in the strict vocational sense) to public service was gradual: York served his two legislative terms while he was pastor of the UCC Congregational Church at River Falls in western Wisconsin.

How the ministry influences York's work is evident partly in the affiliations he has chosen, such as the Good Samaritan board, the state Office of Emergency Energy Assistance, the Association of Homes, even the PSC. "One thing," he says, "is a sensitivity to how events affect people. Individuals. You can visit only so long with elderly folks on very limited incomes before their problems become your problems. In dealing with utility matters, that's very much a part of things."

Pressures from many sides, high and conflicting expectations, are also a fundamental part of utility regulation today. York invokes a pulpit phrase to explain how he keeps his sanity. "You might say I have a very highly developed sense of original sin! A lot of people have very high expectations of human institutions and human interactions that I just don't share."

That observation gently and wryly proclaims that everyone's actions are somewhere flawed, including his own. York is thus pragmatic in his approach to PSC casework. "I don't believe there are any right answers to the questions I face. I'd go so far as to say there aren't any answers at all. There are just the best judgments we can make, given the limited information we have today about the circumstances and the alternatives."

With this view of his responsibility, York feels no need to defend the absolute "rightness" of what he does. Instead, he describes his decisions as "those that other ratepayers would make if they sat where I sit and had access to the information I have." His words closely parallel a classic expression of what economic regulation is supposed to achieve: It constrains the business monopoly as the

Even when there is no single right answer, there is still a best judgment to be made, says this former minister and state legislator. The principle serves him today as chairman of Wisconsin's Public Service Commission and member of EPRI's Advisory Council.

Photos by Kevin Wrobel

marketplace would do if the marketplace were free to act.

York is in charge of the economic regulation of nearly all Wisconsin utilities: electric, gas, telephone, water, and some sewer. In electricity service alone, this means 13 investor-owned companies and 88 municipal agencies. Only the rural cooperative organizations are exempt from PSC regulation.

York's position has become widely familiar, influential, even controversial to a degree that wasn't foreseen when he accepted it just three years ago. Imported oil costs even then had been pushing nationwide electricity rates upward for six or seven years. But only more recently have economic inflation and unemployment combined to make household utility bills the subject of alarm and outright resistance that we had earlier seen at gasoline pumps.

How did York end up in this inherently unpopular position? He says it's basically a matter of practicing what he preached. "For years I said to people in the parish, 'You can't change the circumstances that govern your lives just by sitting back and yelling.' Part of what I believe about our role as citizens is that we should go do those things that we can do. And I had that kind of opportunity."

"A lot of people have very high expectations of human institutions and human interactions that I just don't share."

Improving the advisory role

York's insightful practice of what is desirable and possible in public service is augmented by other interests. He calls himself a technology nut, humbly adding, "Knowing nothing about it, I enjoy all the gimmickry. Get me anywhere near any of it, and I'll ask all sorts of dumb questions!"

But something other than mere fascination with technology made possible his EPRI advisory connection. He became a member of the National Association of Regulatory Utility Commissioners (NARUC) when he took office on the Wisconsin PSC. NARUC, in turn, soon proposed his name for one of the seven utility regulator seats on the EPRI Advisory Council.

EPRI's management and Board of Directors gain special guidance from the Council because its members are drawn from a wide range of U.S. businesses, professions, and interest areas, such as education, science, labor, communications, environmental affairs, medicine, economics, and utility regulation. Regulatory commissioners also come from many interest areas in their home states, so the 7 nominated by NARUC blend in with their 18 Council colleagues. Yet they bring a useful familiarity with the special constraints that go with utilities' monopoly status.

The Advisory Council is a window into EPRI and its technology decision making, a window specified in the Institute's corporate architectural plan. The intent is for outside viewpoints to flow inward through it. But as with all windows, light, sound, and air can pass in either direction. For a number of years, while EPRI was the expression of a still-new concept of industrywide coordination, there was an understandable tendency for EPRI to explain itself, its technologies, and its industry to what was almost a captive audience.

This is changing, and York is among the Council members who are bringing things around. "The question isn't one of carrying weight," he cautions, speaking of executive power and influence. "The question is, Are we giving advice—are we being advisory?"

The Council's feeling, as York expresses it, was that it was being indoctrinated. EPRI was thereby missing the opportunity to learn what others thought of the electric power technology community and what they wanted from it. "Part of the need," says York, "is to pose questions in the framework in which *we* are interested, not the framework in which EPRI deals with its own life."

York is understandably pleased that Council members have good one-on-one relationships with the EPRI staff members. "That wasn't the problem. The problem was, EPRI wasn't getting the interaction that would come if Bob Georgine as a labor leader [AFL–CIO Building and Construction Trades Department president] and I as a regulator were to attack a problem from two different perspectives. That interaction is different from what any of us alone can give EPRI. And that wasn't happening."

Now it can happen. Since the summer of 1981 the organization and conduct of Council affairs have changed. Ad hoc issue groups and subcommittees now exist to meet on other occasions, develop subject matter, and come to Council meetings prepared to lead discussion. Issues may be suggested by the Council or by EPRI staff. York seizes on a hypothetical example, the adoption of new technology by the utility community. "That's an issue the Advisory Council can help with," he says. And the thought releases a flood of related questions.

"Is the process taking place fast enough? What's the regulatory community's influence on it? What are regulators saying to utilities about using new technology? What message are utilities getting? Is it correct? For that matter, is EPRI hearing the correct story? Will this or that specific development stand the test of being put to the regulatory community?"

York pauses, then summarizes. "We are curious about and interested in the technology that EPRI develops. But the Advisory Council's main concern is, How effectively does this R&D organization interface with a world that has only the barest passing interest in what chemical you put on a tree to keep it from growing up into the wires?"

Moving technology along

Some of the obstacles to rapid adoption of technology are subtle. For example, a utility applies the results of EPRI research to some portion of its system and appears to realize benefits and cost savings accordingly, but then reports those savings very conservatively in its public references.

In EPRI's view, such a case history speaks well for the using utility and encourages other utilities to seek the same benefit. But the using utility seems apprehensive that such best-case savings might be taken out of context and that its state regulatory body would immediately call for systemwide adoption of the same item. Such a prospect is alarming to the utility when existing equipment has not yet served its planned economic life and returned its cost.

York acknowledges the power of regulators. "The utility can—or must—do only what its regulators prescribe. But the preponderance of regulation retards the purchase of new equipment. The utility doesn't work on a competitive basis, where it has to come out with new technology in order to keep ahead. The utility has a responsibility to keep obsolescence at a minimum.

"Look at utility management," York adds. "Is there any more conservative group in the country? These are not risk-takers. We won't let them take risks."

There probably are occasions of misplaced or premature regulatory pressure, York admits. "You get commissioners who don't really understand their job or the job of the utility. And, people ride hobbyhorses; that is, if they have a particular interest in something they think is right, they do what they can to see that all the utilities do it."

When utilities seem slow to effect change, it may be partly rooted in habit or preference, York notes. Then, he says with fine irony, "I'm not surprised when they use the commission as an excuse for not doing something that they don't want to do anyway. We had an instance where a utility was in financial trouble, and we moved up its rate case to try to deal with the problem. Meantime, the utility had an annual stockholders' meeting, and the president reported, 'We're in trouble because the commission isn't processing our case fast enough.' Commissions are a natural scapegoat," York concludes.

Technology transfer is also influenced by EPRI's dual relationship with its members: utilities are both its owners and its clientele. Can EPRI avoid spoonfeeding only what members want to hear? York acknowledges that human nature is at work here. "I mean, you figure out who is paying your salary and you try to give him what will make him happy."

But he seems equally certain that utilities expect EPRI to have a life of its own,

"The need is to pose questions in the framework in which we are most interested, not the framework in which EPRI deals with its own life."

an independence of judgment and expertise. "Just because they are both EPRI's owners and its market doesn't mean that they have all wisdom." York uses an analogy to describe his thinking.

"Say you retain an attorney on a tax matter. You want him to accomplish a result. But you expect him to have, or develop, some expertise in the matter that doesn't come directly from you. He'll go to some tax workshops, for example; he'll look for what's been done elsewhere."

York emphatically includes the Advisory Council among the resources that utilities expect EPRI to use. "They expect EPRI to be seeking knowledge elsewhere. Not just specific technology; not just saying to a contractor, 'Develop a better coal gasification plant,' but also turning to the Council to explore just where and how technology R&D for utilities should fit into the total universe of things."

There is another aspect, York notes. "Utilities are very parochial—very, very local. They have very different sets of problems, depending on their generation mix, their geography, their regulatory climate." He thus seems certain that at least some of EPRI's R&D results are bound to be disputed (or at least found inapplicable) by some of its members.

York senses that EPRI constantly sells its members, its owners, on the validity of what it is doing. "And with that selling, EPRI is buying some flexibility, some freedom to try things. But if you're not failing part of the time, you're not doing R&D, in my judgment. If everything works, you're not asking tough enough questions."

"The preponderance of regulation retards the purchase of new equipment. The utility has a responsibility to keep obsolescence at a minimum."

The utility that pays the bill probably wants a higher percentage of success than the researcher back in the laboratory, in York's opinion. He calls it a dynamic situation, even a balancing act, and says he has exactly the same experience. "I'd like to think utilities have some respect for the manner in which I administer the work of the commission. But if they say it nicely in public, I'm in trouble. If the utilities aren't complaining, then the consumer groups think I'm not doing my job!"

Finding the public interest

In the course of ranging through York's three years as a utility regulator and EPRI adviser, many observations, ideas, and conclusions pop up, some from the context of discussion, others just in passing. For example, because investor-owned utilities earn their profit basically as a return on plant investment, is it true that they have a single-minded motivation to build? "They used to, but they don't any more. Now it costs more to build power plants than it does to install energy-saving equipment and run conservation programs. It's because of interest costs, construction costs, that kind of thing."

Does the public know this? "No," says York flatly. Going on quickly, he adds, "It's an interesting split. On the service side, the public sees the utility as totally reliable, totally dependable, and a good neighbor. But on the financial side, when it comes to rates, they see him as the bad guy, a rip-off, greedy."

York points out that the contradiction can be personally embittering, particularly for the people now in utility management. "Until the mid-1970s, a guy moved up the ladder in the company, and at the same time he moved toward more and more community acceptance and leadership. But his world turned upside down in the late 1970s. He discovered that because he was at the top of the ladder, he was now the bad guy. It's been tough."

The contradictory perceptions of electricity dependability as good and electricity rates as bad can be at least partly resolved, York believes. He has come to realize that it is no longer true that all customers want fully available electricity at all times, regardless of the cost. "There are real differences in demand for availability at the point of delivery. I want a whole lot higher level of availability for my refrigerator than I do for my water heater, a lot better for my color TV than for my air conditioner."

This tells York, as a regulator, that customers have more flexibility than previously thought, more variety in their interest and economic options. He sees individual on-off controls, remotely pulsed by the utility, sometime in the future, with lower rates for the interruptible electricity. "We don't necessarily have to go the single route of building power plants to meet demand growth. We can use economic means to slow it, to reduce the peaks."

York reflects a bit on what he has said. "You know, one of the advantages of coming into utility regulation from the outside is that I'm not encumbered with the baggage of history. It's a bigger disadvantage than advantage," he admits, "but sometimes it is an advantage. Because I don't have background in the industry, perhaps I am able to see this idea of customer flexibility a little more quickly than others."

His work in utility regulation has honed York's sense of what is and what is not the public interest; but it has not made the definition or its acceptance any easier. "There isn't any objective set of words. And it's not like saying you mix some metals together and you come up with a certain alloy, and that's the public interest.

"The public interest is where all the special interests converge. But it may not be a position satisfactory to any one of them." York suggests the example of a utility that claims it must have an 18% return on equity to survive, while a consumer group contends that 13% is plenty. "If the matter were in a law court," says York, "a judge or jury would have to select either 18% or 13%. But a public interest consideration may arrive at 15% or 16%, taking into account stockholders, ratepayers, and society as a whole."

Process versus pronouncements

York reminds us that regulatory commission decisions don't routinely win popularity contests. A highly politicized Wisconsin example comes to his mind, the cancellation of the Koshkonong nuclear power plant. "We said the utility had prudently planned the plant, but that circumstances had thereafter changed. So our commission decision provided for the utility to get back what it had spent for the planning process. Antinuclear people were very happy to see the plant canceled, but some of them were very unhappy because of our decision on the planning costs."

Not just in regulatory work, but for any government decision maker, it is quickly apparent that people with the minority viewpoint on an issue are looking for a statesman, someone who will rise above politics and provide leadership. People on the majority side, of course, want someone who will be truly representative, responsive to the public will. Inevitably, York has his own opinions. What does he do with them? For the most part, he relies on the public process, rather than on his private pronouncements, to illuminate issues.

"The legislature tells me what my job is, and I think that's appropriate. As a regulator, I ought to be bound by the law. I don't think appointed people ought to be setting themselves above it.

"For example," York goes on, "I am preempted by federal law from dealing with nuclear power safety questions. That's an NRC matter and I keep my nose out of it."

York says he is accused of drawing lines around a little legal box as a way of staying out of trouble. But, he observes, any time he inadvertently sticks his toe outside that so-called box, he can get taken to court. "There's a perpetual problem of trying to do your assigned task within your little box."

And here York returns to the matter of making the best judgment possible with the information that is available. "I bear a serious responsibility for the decisions I make. They're the ones that other ratepayers would make if they sat where I sit. . . . " York is a little wistful as he concludes, "It makes me a consumer representative, though nobody describes me that way." ■

This profile was written by Ralph Whitaker and is based on an interview with Stanley York.

"If you're not failing part of the time, you're not doing R&D. If everything works, you're not asking tough enough questions."

OSTP: Advice to the President

The Office of Science and Technology Policy gives guidance to the president on issues of environmental and energy-related policy, as well as on national security and basic research.

Confronted daily with the need to make decisions that have far-reaching policy implications, the president must draw on the expertise of many Washington advisers. For advice on scientific and technical subjects, the president's primary resource is the Office of Science and Technology Policy (OSTP).

This office has origins in the Office of Science and Technology (OST), created as an advisory office to President Kennedy in 1962 to augment the position of science adviser established earlier by President Eisenhower. Dissatisfied with the function and contributions of the science office, President Nixon abolished it in 1973; President Ford reestablished the office through the Presidential Science and Technology Advisory Organization Act of 1976.

With strong congressional support, OSTP was established to fulfill certain scientific advisory roles considered integral to the welfare, security, and economic well-being of the nation. As authorized by the 1976 legislation, the director serves concurrently with the president as his science adviser. In the Reagan administration, OSTP is directed by George Keyworth, formerly director of the Laser Fusion Division of the Los Alamos Scientific Laboratory.

In its present form, OSTP provides the president, as well as Congress, with analyses of selected issues to assist in the executive decision-making process. The office also provides information for the review, analysis, and coordination of all federal R&D programs and budget items with the president and the director of the Office of Management and Budget. At the request of Congress, OSTP produces an annual report and a five-year outlook on science and technology.

Office Organization

OSTP is divided into five major functional groups—National Security and Space, International Affairs, General Science, Life Science and Institutional Relations, and Energy and Natural Resources. Each of the five areas is headed by an assistant director.

With only 6–10 employees assigned to each of the five divisions, the OSTP staff is relatively small. However, OSTP relies on loaned employees and ongoing or completed studies from other federal groups to assist in the completion of its work. Frequently an assistant director will form a working group of members of his staff and staff from other agencies to examine an issue of particular relevance. By acting in a management or oversight capacity and by avoiding duplication of work already in progress, the OSTP is able to fulfill its duties with a small number of permanent staff. According to John Marcum, assistant director for Energy and Natural Resources, "By minimizing our operational responsibilities, we avoid getting involved in coordinating agency activities. We are very pleased with the current size and structure and are able to provide the president and other senior staff members with advice on issues that involve R&D science and technology questions."

Of the five divisions, Energy and Natural Resources is the group that deals with the policy questions of most relevance to the utility industry—oil, coal, and gas supplies; alternative energy sources; nuclear power; and environmental issues. Marcum comments, "Our function is to be sure the president and his advisers are aware of opportunities where they exist and of problems when they arise. In addition, they need to be advised in a timely and comprehensive manner on issues with scientific and technical ramifications to assist them in arriving at sound policy decisions."

Because of the scope of these objectives, the energy issues Marcum's staff is principally investigating have involved a mix of critical technologic, scientific, economic, and political issues. The division is heavily involved in the Reagan Administration's efforts to restructure the energy program, including the legislative proposal to dismantle the Department of Energy, and is responsible for preparing scientific and technical inputs for the FY1981, 1982, and 1983 budgets. In these capacities, Energy and Natural Resources is working with OMB and DOE on all key energy R&D issues, including alternative energy technologies, fast breeder reactors, coal issues, and synthetic fuels.

In some areas, the Energy and Natural Resources staff deals with policy questions that have a direct effect on the electric utility industry. For example, in two studies that examine the overall U.S. energy situation and appropriate federal role, Marcum's staff is currently looking at possible federal initiatives involving the electric utility and nuclear power industries; two other areas of emphasis involve the state-of-the-art research prognosis for atmospheric carbon dioxide and acid precipitation. These four issues are of particular significance to the industry.

Power Industries

In the first study, the Energy and Natural Resources staff is interacting with a working group of President Reagan's cabinet council to study the factors affecting the electric utility industry's financial health. The group will make recommendations relating to the resolution of the financial problems and consider the regulatory measures that should be instituted, the problems that are within the purview of the utility industry itself, and the extent to which the federal government should be involved in resolving the problems. This working group will provide a complete analysis of these issues for cabinet council review.

Marcum

In a parallel effort, another panel is looking at the underlying problems hampering the growth of the nuclear power industry. "This office has been, and will continue to be, intimately involved in questions relating to nuclear power, especially with regard to the initiatives that President Reagan directed last July and October. The first area deals primarily with the international side of nuclear power, specifically nonproliferation and export-related questions. The second issue deals with domestic nuclear power and the steps needed to encourage a nuclear industry recovery," Marcum explains.

As one of several steps planned to restore nuclear power as a viable source of energy, President Reagan directed the secretary of DOE and the director of OSTP to report to him by September 30, 1982, on the obstacles impeding the increased use of nuclear power and what is needed to remove them. Consultations were initiated last February with Vice President Bush, DOE Secretary Edwards, Commerce Secretary Baldridge, OSTP Director George Keyworth, and key representatives of the electric utility industry, nuclear power supply companies, investment firms, regulatory commissions, and the university community to discuss the constraints on the nuclear industry. Some key questions discussed related to how competitive our nuclear power industry is with those abroad and what financial incentives could stimulate greater competition. The results of these meetings, along with subsequent meetings and analyses from other studies, will be the basis for the September report to the president.

Exploring Specific Issues

The two studies just described were initiated in response to a presidential request; however, OSTP also undertakes reviews at the behest of Congress. For example, in the Energy Security Act of 1980, Congress required OSTP to undertake a comprehensive study of the environmental effects of the buildup of carbon dioxide in the atmosphere.

As mandated in the act, OSTP, through the Energy and Natural Resources group, is working in conjunction with the National Academy of Sciences (NAS) to assess this problem, to examine the quality and effectiveness of current federal carbon dioxide research efforts, and to recommend ways in which national and international research programs can be structured to be of most benefit to government policy makers.

The study, being conducted by the National Research Council of NAS with joint OSTP, DOE, and National Science Foundation (NSF) funds, will provide a basic source document for OSTP's formation of policy. "This program illustrates the type of work-study OSTP can manage, basically under our direction and oversight, without excess staff participation. Of course, no matter where the study group is housed," explains Marcum, "we will objectively consider its findings and incorporate them into our advice and recommendations to the president."

At the request of the Council on Environmental Quality, the Environmental Protection Agency, and the departments of State and Energy, OSTP is also directing the work of a scientific panel of experts on acid precipitation. However, unlike the carbon dioxide study, OSTP is conducting the acid precipitation study in-house because of the sensitivity of the issue. As its primary function, this panel is undertaking a comprehensive peer review of all research documents that have been generated under the joint United States–Canada Task Force, pursuant to presidents Reagan and Trudeau's Memorandum of Intent (the U.S.–Canada Transboundary Agreement of August 1980).

This peer review, with NAS and NSF support and advice, will provide the basis for subsequent policy discussions between the two countries. Marcum explains, "There will be frequent consultations between our panel and its counterparts in Canada. By the end of the study, we will be in a better position to understand the realities and the scientific and technical dimensions of the acid precipitation problem and to assess the recommendations that should be given for policy decisions." The panel is expected to begin its review of the documents within the next two months.

White House Advisory Council

In addition to other federal departments and agencies, OSTP has another resource on which to rely for information and advice: the White House Science Council (WHSC). The 13-member council was established in 1981 to play a role similar to that of the President's Science Advisory Council (PSAC), now disbanded. According to Marcum, "PSAC was a group of very senior, competent people, who reported to the president, essentially through the science adviser. However, they frequently acted independently and were much less focused in terms of ongoing policy directions. In this role, PSAC received criticism that contributed to President Nixon's decision in 1973 to abolish the OST."

In contrast to PSAC, George Keyworth established WHSC to function as an advisory appendage of OSTP. It reviews issues that are selected by Keyworth and reports to OSTP, rather than to the president. Composed of distinguished members of the academic, industrial, and scientific communities, the council meets every few months to review complex science and technical questions and, where necessary, to form ad hoc panels to look at specific issues in greater detail. Marcum comments, "We see it as a valuable institution in that it provides the president with additional advice from a group of high-level members of the private sector and the academic community, who often have a more diverse range of viewpoints than can be gathered solely through the OSTP and other agency staff."

Among its many reviews, WHSC is currently undertaking a study to define the role and mission of the national laboratories. The council's goal is to show how the laboratories can be strengthened and streamlined to meet current R&D needs. Two questions the council will examine are whether the laboratories are functioning as originally planned and whether they have outlived their original mission. It will also discuss ways in which to improve technology transfer from the research institutions to the industrial sector. Other WHSC studies cover such diverse topics as civil air transport and military technology issues.

OSTP seeks input not only from WHSC but also from other federal, private, academic, and scientific resources to provide a sound and knowledgeable basis for the advice it is called on to provide to the president. Marcum stresses, "We need to ensure that government programs facilitate, rather than impede, closer cooperation with our research institutions, national laboratories, and academic communities. The more direct the interaction between industry and these research centers, the more quickly we can inject results into the marketplace. In this regard, we work with the private sector to ensure that the federal role is properly focused in areas where it is really needed. During this decade, the investment required of the private energy sector as a whole is anticipated to be about $2 trillion. Our role is to ensure that the far smaller federal R&D budget is effectively utilized in long-term, high-risk technology and in facilitating the private investment needed in the energy sector. This administration is therefore attempting to create a better economic environment through tax and patent policies, investor incentives, and science and technology initiatives that will help the energy and utility industry meet this tremendous capital requirement." ■

This article was written by Ellie Hollander, Washington Office.

AFBC Plant Begins Operations at TVA

Operation of a $68 million pilot facility marks the most significant effort to date toward developing AFBC for utility use.

Tennessee Valley Authority's 20-MW atmospheric fluidized-bed combustion (AFBC) boiler pilot plant began full operations in June, kicking off four years of tests to be performed under joint EPRI–TVA sponsorship.

Start of the operational test phase wraps up a two-year preparatory effort that involved operator training and the development of computer systems and test procedures.

The plant, located at TVA's Shawnee Steam Plant Reservation near Paducah, Kentucky, is the final developmental step before the design and construction of one or more 100–200-MW commercial AFBC demonstrations, already in initial planning stages. The test program will run through mid-1986 and is expected to cost $28.5 million.

AFBC is a concept whereby fuel is burned in a limestone bed that is suspended by air fed into the bottom of the boiler at atmospheric pressure. The air causes the limestone particles to percolate like a liquid, hence the term *fluidized bed.*

Although AFBC technology itself is not new (numerous AFBC boilers are in operation worldwide), utility application of the concept is relatively recent. Research now indicates that AFBC could be a major advance in coal combustion for utilities for a variety of reasons.

For one, the AFBC process produces far fewer emissions than conventional boilers, eliminating the need for much of the expensive air quality control equipment typically used. The limestone bed reacts with sulfur dioxide to produce calcium sulfate, which is removed from the boiler and disposed of as a solid. In addition, because of the relatively low operating temperature of the boiler (about 1550°F; 843°C), far less nitrogen oxide is produced.

The lower operating temperature also has a positive impact on plant performance and reliability because 1550°F is well below the temperature at which coal ash melts. The lower temperature eliminates the ash slagging and fouling problems that currently limit fuel flexibility in pulverized-coal and stoker-fired furnaces. In fact, because the AFBC boiler operates below the ash fusion temperature, its design is essentially independent of the ash properties of the fuel. As a result, AFBC offers fuel flexibility not possible with standard boilers.

The TVA pilot plant is designed to burn inexpensive, high-sulfur Kentucky No. 9 coal, but plans call for testing other fuels, such as lignite and subbituminous coals. The plant could potentially burn other low-grade fuels as well (e.g., coal-washing residues, coal-mining wastes, refinery wastes, wood wastes, and refuse-derived fuel).

The first two years of testing at the Paducah plant will be devoted to evaluating various methods for feeding coal and limestone into the process and enhancing the automatic process control capabilities so that AFBC can be used for cycling and shifting, as well as for base-load applications. The plant's computerized data acquisition and control system will enable researchers to evaluate plant performance with an eye toward scale-up of the concept to commercial size.

A utility group, organized by TVA and EPRI, is reviewing the test program and advising researchers on the direction of the work. On-site participation in the testing by utility engineers and plant operators is being planned. ■

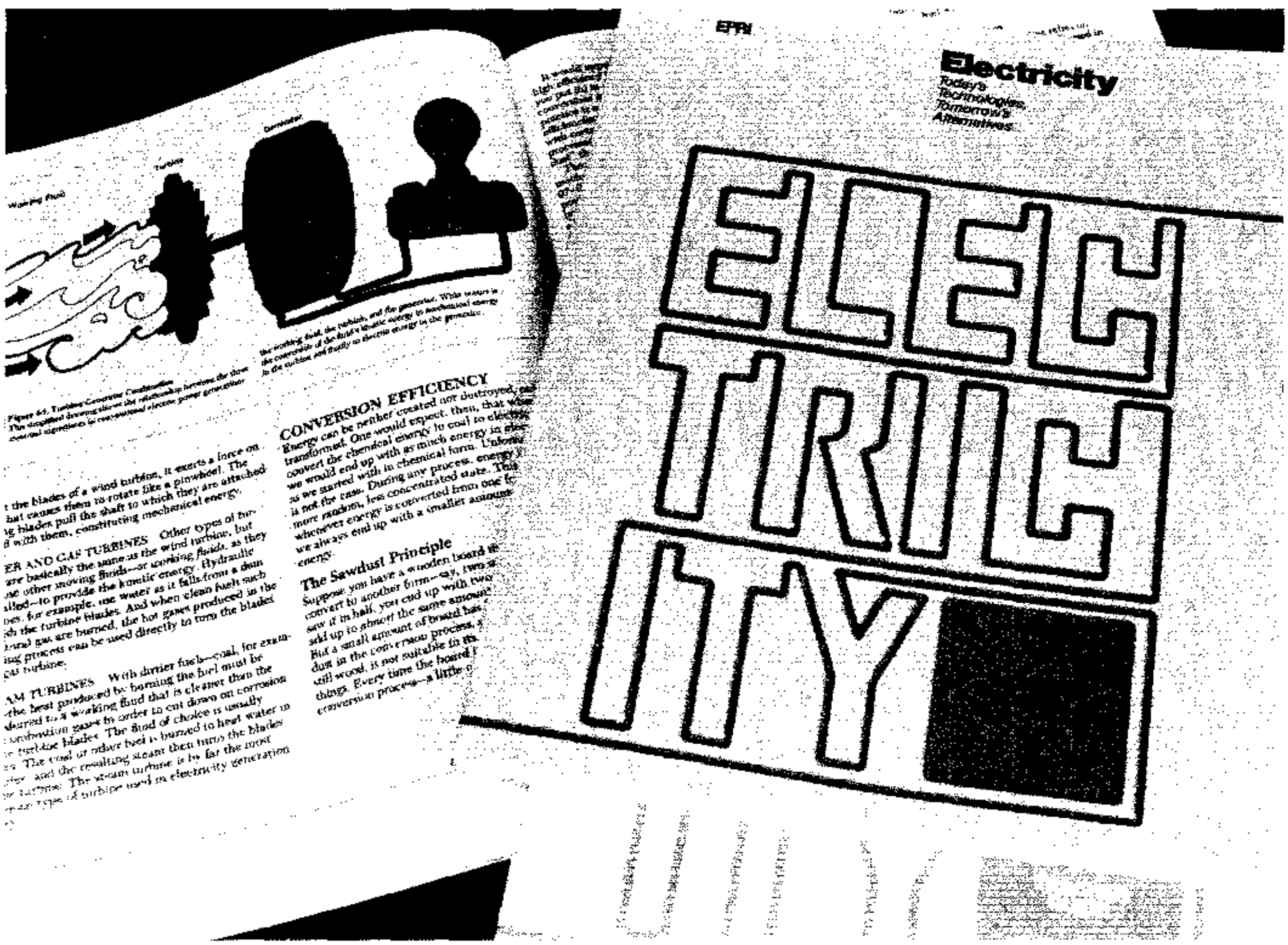
Electricity Book Revised

The revised, updated edition of *Electricity: Today's Technologies, Tomorrow's Alternatives* is now available. The book, first published in 1981, is a readable survey of the critical technical issues that relate to the supply and demand for electric power. A teacher's guide keyed to the new edition is also available to help educators put the book to work in high school and junior college classrooms.

Produced by EPRI staff on behalf of the electric utility industry, the book provides a complete yet simple and understandable introduction to the problems associated with the production and use of electric energy in the modern world. It is authoritative and up-to-date, presenting facts to help readers make informed judgments about basic energy issues that affect the quality of their lives.

The major premise of the book is that electricity is the fastest growing energy form in the United States. Today, about one-third of our energy is converted to electricity before it is used. By the turn of the century, as much as half of our total energy may be produced in the nation's electric utility power plants. Descriptions of technologies for producing and delivering electricity and discussions of related energy issues show how we will get from today's forecasts to tomorrow's realities.

Specific topics covered in the book include energy use, demand, and supply; principles of electric power generation; present and future generating options; electricity storage and delivery; environmental concerns; and planning for the future. Prices for *Electricity* are as follows.



Quantity	Price per Volume
1–4	$7.95
5–99	5.50
100–999	4.50
1000–4999	3.50
5000 and up	Prices on request

Teacher's guides are $1 each; one will be provided free with each classroom order of 30 copies. Orders may be placed with William Kaufmann, Inc., 95 First Street, Los Altos, California 94022. ■

Culler Named to Federal Advisory Board

Secretary of Energy James B. Edwards has appointed EPRI President Floyd L. Culler to fill a vacancy on the Energy Advisory Board, created in 1978 to advise the secretary on R&D programs and provide guidance on long-term scientific policy issues.

Culler, a recognized expert in the field of nuclear energy, has wide experience in management and application of R&D, having served 30 years at Oak Ridge National Laboratory before joining EPRI in 1978. His scientific honors and awards include the International Atoms for Peace Award, the E. O. Lawrence Memorial Award, election to the National Academy of Engineering, and appointment as a fellow in the American Nuclear Society.

Secretary Edwards noted that Culler's appointment "further enhances the expertise in electric utility–related R&D available to the Department of Energy." He added that Culler's "broad technical knowledge in energy-related matters will maintain the board's balance of experience, expertise, and points of view represented." Other members of the 22-member board have backgrounds in conservation, energy production, environmental protection, law, economics, medicine, and research management. ■

CCTF Dedication

About 70 people were on hand June 10 for the formal dedication of EPRI's Coal Cleaning Test Facility, the nation's newest, most advanced coal-cleaning research, development, and demonstration plant ("Cleaner Coal for Power Plants," *EPRI Journal*, June 1982, p. 24). Located in Homer City, Pennsylvania, the multimillion-dollar plant is being sponsored by EPRI, Pennsylvania Electric Co. (Penelec), New York State Electric & Gas Corp. (NYSEG), and Empire State Electric Energy Research Corp. (Eseerco).

The dedication, which included a tour of the facility, was held in connection with a series of Coal Combustion Systems (CCS) Division advisory meetings. The industry advisers received special recognition during the ceremonies for their important role in the facility's successful development.

Kurt Yeager, director of EPRI's CCS Division, welcomed participants in the dedication at a luncheon meeting, and S. Robert Hart, vice president for Research and Development at Southern Company Services, Inc., and chairman of the CCS Division Committee, spoke on the importance of CCTF to the utility industry. Talks were also given by Robert Wise, vice president for Generation Engineering and Support at Penelec; George Watkins, executive director of Eseerco; and Frank Carney, vice president for Research and Development at NYSEG.

Industry studies show that cleaning coal before combustion can substantially reduce air pollutant emissions and increase power plant performance and reliability. An increase of just 1% in availability for a 1000-MW power plant could result in an estimated cost savings of about $1.5 million a year. CCTF will be used to help develop and demonstrate optimal coal-cleaning equipment and processes and will also offer training for operators and engineers. ■

Speakers at the Coal Cleaning Test Facility dedication (from left): S. Robert Hart, George Watkins, Frank Carney, and Robert Wise.

Updated Transmission Line Reference Book

An updated, expanded edition of the *Transmission Line Reference Book, 345 kV and Above,* was recently published by EPRI. The 625-page book, widely known as the red book, is a data source for the electrical design of EHV and UHV trans-edition represents a substantial expansion in the technical content of each of the topics covered in the first edition (published in 1975). New electrical design items have also been introduced.
mission lines up to 1500 kV. This second

Richard Kennon, program manager for Overhead Transmission Lines in EPRI's Electrical Systems Division, explains that the broader scope of the new edition will make the reference book more valuable to the beginning engineer, as well as to the experienced line designer.

Four major design areas are treated: insulation design, corona performance, electric and magnetic fields, and circuit performance (including conductor characteristics). In each area, a common set of base case circuits is analyzed to help the design engineer understand and become sensitive to the items affecting design. The means of measuring each performance factor are also explored.

According to Kennon, "The red book has become the most widely used transmission line reference book in the industry. The new edition is better as it includes five years of new test results."

The addition of a new chapter that summarizes the book and introduces line design in a tutorial way also contributes to the second edition's effectiveness. "In fact," Kennon stresses, "Anyone who has not had extensive experience with the first edition should start the new edition by reading the summary chapter."

The book, priced at $55.00, may be ordered through the Research Reports Center. ■

CALENDAR

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

AUGUST

25–27
Incipient Failure Detection for Fossil Plant Components
Hartford, Connecticut
Contact: Anthony Armor (415) 855-2961

25–27
Solar and Wind Power, 1982 Status and Outlook
Providence, Rhode Island
Contact: Edgar A. DeMeo (415) 855-2159

SEPTEMBER

8–10
Workshop: Steam Turbine Bearings and Rotor Dynamics
Detroit, Michigan
Contact: Tom McCloskey (415) 855-2655

14–15
Performing Power Plant Reliability and Availability Analyses
Palo Alto, California
Contact: Jerome Weiss (415) 855-2495

20–22
International Conference: Compressed-Air Energy Storage and Underground Pumped Hydro
San Francisco, California
Contact: Robert Schainker (415) 855-2549

21–22
Seminar: Cathodic Protection of Bare Copper Neutral Conductors on URD Cables
Kansas City, Missouri
Contact: Thomas Kendrew (415) 855-2317

OCTOBER

3–7
2d International Workshop: Impact of Hydrogen on Water Reactor Safety
Albuquerque, New Mexico
Contact: Loren Thompson (415) 855-2964

7–8
Cooling-Tower Plume Prediction
Chicago, Illinois
Contact: John Bartz (415) 855-2851

12–13
Workshop: Evaluation of Small-Hydro Sites
Chicago, Illinois
Contact: Charles Sullivan (415) 855-8948

13–14
Seminar: Cathodic Protection of Bare Copper Neutral Conductors on URD Cables
Arlington, Virginia
Contact: Thomas Kendrew (415) 855-2317

13–15
Transmission Line Grounding
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

13–15
Seminar: Fuel Supply
St. Louis, Missouri
Contact: Jeremy Platt (415) 855-2628

14–15
Seminar: Cooling Lake Multiple-Use Assessment
Chicago, Illinois
Contact: Robert Kawaratani (415) 855-2969

18–20
Substation Grounding
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

25–26
Seminar: Turbine Missile Effects in Nuclear Power Plants
Palo Alto, California
Contact: George Sliter (415) 855-2081

25–27
7th International Conference on Fluidized-Bed Combustion
Philadelphia, Pennsylvania
Contact: Shelton Ehrlich (415) 855-2444

27–28
11th Semiannual Meeting: ARMP Users Group
Omaha, Nebraska
Contact: Walter Eich (415) 855-2090

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

CYCLING EFFECTS ON POWER PLANT COMPONENTS

An increasing number of large fossil-fuel-fired generating units are being operated in a cycling mode. This operating strategy has developed because of the increase in nuclear-powered baseload capacity and rising oil prices. However, cyclic duty causes thermal stress cycles on major boiler and turbine components, which can result in distortion, fatigue, and/or high-temperature damage, significantly reducing unit reliability and service lifetime. EPRI research has identified the critical factors and components controlling cyclic operation and has developed starting, loading, and shutdown procedures and control techniques for improved cycling unit reliability, efficiency, and service life.

During startup and load changing, steam power plant components are subjected to rapid temperature changes that result from heat transferred from the steam. The metal sections in modern high-pressure, large-capacity units are very thick, which causes large internal-temperature gradients and, in turn, high thermally induced stresses. At full operating temperature, the materials are subject to creep or permanent deformation, and the imposition of thermal stress cycles may cause repeated irreversible deformation called rachetting and low-cycle fatigue. Units designed for baseload operation may have only limited capacity for absorbing such damage and normally are not able to start quickly.

Limited starting and loading rates impose economic penalties and hinder system flexibility. More and more utilities, therefore, control units by computer systems that read critical temperatures and rates of temperature change and choose between minimum economic penalty and acceptable thermal stress. Further, boiler manufacturers are incorporating superheater and reheater bypass systems, which, together with variable-pressure turbine operation, seek to minimize thermal stresses.

Computer control system design relies on the ability to mathematically model plant thermoelastic behavior, so that a relatively few measurements permit comprehensive evaluation of component states. The major plant vendors have developed such models, which have been validated to a greater or lesser degree by direct measurement. Direct data from rotating elements are limited, however, as is the range of startup conditions under which all data have been obtained.

Almost all European fossil-fuel-fired, reheat units, including supercritical units, are designed for load cycling to satisfy their system load requirements. This has resulted in different design and operating philosophies, including spiral-wound, variable-pressure boilers, full-arc admission turbines, and turbine bypass systems. EPRI is studying the European operating practices in conjunction with U.S. cycling operation procedures and control techniques, EPRI research is investigating ways to provide improved mathematical models and evaluation of retrofit technology for utility use. Five major investigations are studying existing baseload units, existing cycling units, universal pressure boilers, control systems, and turbine bypass systems.

One project (with Tennessee Valley Authority) has examined cycling of high-pressure steam generating units with drum boilers at its Widows Creek plant (CS-2340). This work identified and quantified cycling operation factors that contribute to loss of reliability and useful life and determined operating procedures and/or control techniques that might minimize these detrimental effects.

The objectives of this project were the following.

- Identify critical components of drum-type baseload design units subjected to severe thermal stresses during cycling operation and determine by field tests realistic boundary conditions that produce these stresses

- Assess existing operating or control strategies or develop new ones that optimize the trade-off between the unit reliability and service life losses and the system energy costs associated with cycling

The most significant result of this research effort was the development, validation, and documentation of a mathematical model of the study boiler's transient behavior during startup, load regulation, and shutdown. Before the model was validated by actual test data, it was used to evaluate the proposed test program. The original test program recommended 18 cycling tests to provide data necessary for analysis. These test scenarios were run on the boiler model and indicated that only 3 tests would be necessary to satisfy the project data needs, significantly reducing project cost and concerns of the operating department.

The model, validated by the data obtained from the cyclic tests of the study boiler, was used to determine which metal parts are subjected to severe thermal stresses and the times stresses occur during typical startup operations. These components for a boiler of this design were found to be the economizer inlet header, superheater platen outlet header, and superheater horizontal outlet header. The boiler model was used in conjunction with the turbine manufacturer's starting and loading charts (which yield the corresponding fraction of turbine life used per start) to obtain an optimal boiler-turbine starting and loading procedure for operator use. Results of this project clearly demonstrate that models can be very cost-effective tools for analyzing real-world operational as well as design problems.

A second project (with Westinghouse Electric Corp.) tested cycling of Commonwealth Edison Co.'s Collins station Unit 5 to improve the reliability and economics of units designed for cyclic operation (RP911).

The scope included a substantial instrumentation effort, analytic model development, and cyclic testing. The study also developed specific cyclic operating recommendations for the Collins station Unit 5 and generic cycling guidelines for utility use.

During cyclic testing at the Collins station an unattended data acquisition system continuously monitored 249 variables and stored the data on magnetic tapes for a period of 15 months. A series of data reduction programs provided summaries of the operation on a daily and a complete project basis. The analysis techniques used to predict turbine component temperature distributions were validated by using measurements of both stationary component and rotor metal temperatures. The rotor bore measurements were obtained by using radio telemetry, the first time such measurements had been taken on an operating steam turbine. These temperature distributions were used as the basis for thermal stress analysis of cyclic operation. The data were analyzed by using various computerized heat conduction programs. Heat transfer coefficient correlations agreed well with measured data. The comparison between calculated and measured first-stage rotor bore temperature is shown in Figure 1. Both thermocouples showed excellent agreement with calculated results up to the time the turbine reached rated speed.

In addition, a boiler model was developed for studying transients in cyclic operation. The model was extensively detailed for the boiler components but simplified for the turbine and feedwater system. This modeling and validation data collection effort represented a significant step toward successful transient modeling of cyclic duty boilers.

A series of eight cyclic operation tests were conducted to examine various operation strategies. The cyclic life expenditure of the turbine and boiler was estimated for these transients either from direct temperature measurement or from calculations. The fuel flows of these tests were also compared to identify major variations during test startup and loading phases. Based on transient analysis and on a combination of economics, cyclic life expenditure, and plant operating preference, a recommended operating procedure for the Collins station unit was developed. These recommendations attempted to maximize the advantages of the equipment in the station.

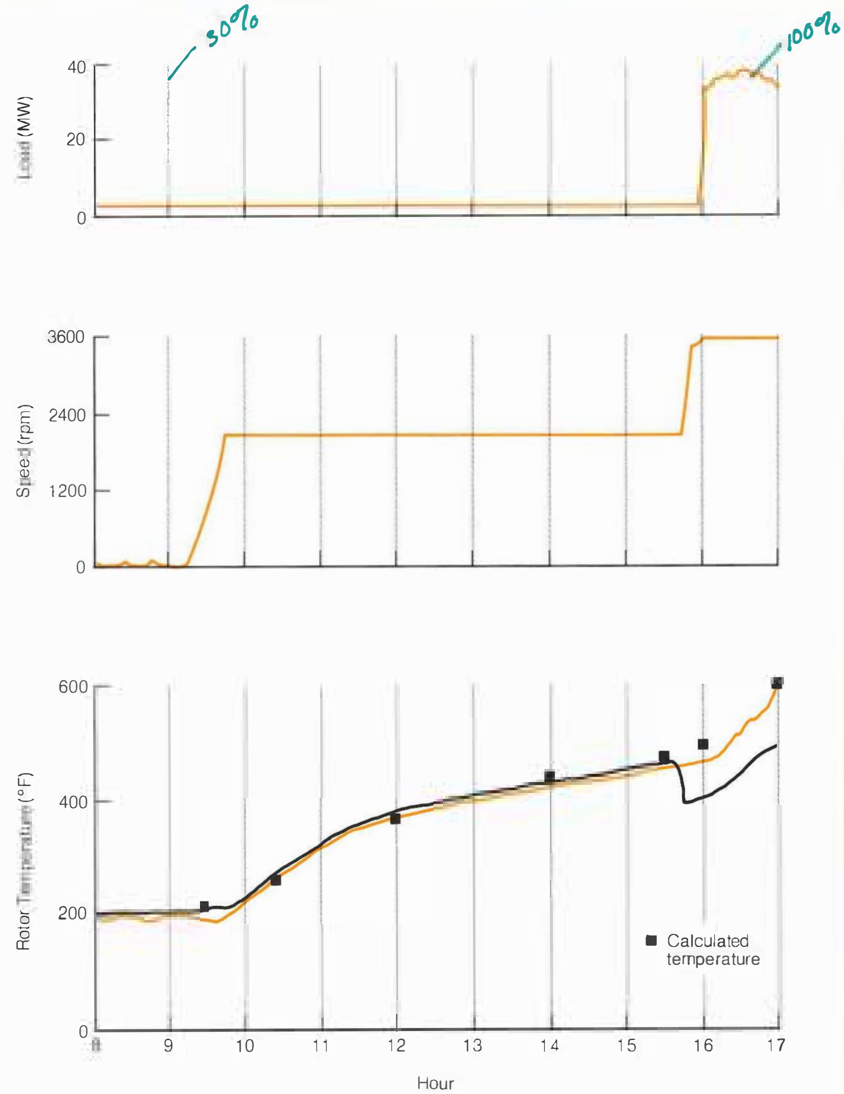
The experience gained from the Collins station Unit 5 tests and additional calculations were the basis for a series of operating recommendations developed for the utility industry. These recommendations are broad in scope and attempt to define factors that should be considered when designing a cyclic duty plant or when converting an existing plant to cyclic duty. The validations of the temperature distribution analysis technique, the boiler modeling effort, and the cyclic operation test experience provide an excellent basis for analyzing cyclic operation at any plant.

The test and data analysis program at Collins station Unit 5 has demonstrated that improvements in the reliability and economics of cyclic plant operation is possible. The data developed in this program are available for independent analysis by the industry; the final report is being prepared and will be available later this year. There are several important conclusions to this study.

- Reliable cyclic operation does not require a compromise with operating efficiency. The hybrid operating mode should be employed at as many plants as possible. Rapid load following may require single-valve, sliding pressure operation.

- Dual pressure combined with hybrid operation can be advantageous for startup and shutdown.

Figure 1 Comparison of calculated and measured high-pressure rotor temperatures. Both thermocouple temperature measurements validated the calculated measurement until the machine reached rated speed. At this time, one thermocouple (black) illustrated speed sensitivity.



- Good training, maintenance, and operator-control interface greatly influence cyclic operation and should be emphasized.

- Temperature control during loading is extremely difficult. However, more flexible control systems can reduce this problem.

- Rotor thermal stresses can be predicted with modern computer techniques and the heat transfer analysis techniques validated in this program.

A third project (with Babcock & Wilcox Co.) studied a universal pressure boiler (CS-2438). This project was directed at identifying boiler system modifications that will allow existing once-through, subcritical B&W boilers to satisfy utility system cycling requirements.

There were two specific objectives. One was to evaluate the cycling performance of a 380-MW, 2400-psi (16.5-MPa) unit at Boston Edison Co.'s New Boston station in the operating modes of cold start, hot start after overnight shutdown, boiler-fired on bypass operation with turbine off-line, hot restart after trip, and load maneuvering from 20% to full load. The second objective was to determine boiler and/or steam generating system design changes that would permit daily on/off cycling with rapid response to system load demands.

Analysis of the test data demonstrated difficulties in controlling the rate of temperature change in boiler pressure components and in maintaining tube-metal and fluid temperatures within design limits in all cycling modes of operation except load changes above 40% load. Startup times were also prolonged because of water quality limitations.

Study unit design modifications to minimize cycling capability limitations resulted in recommendations for three levels of cycling service. Level 1 is load cycling from 40% to full load; level 2 is load cycling from 20% to full load; and level 3 is daily on/off cycling over the full-load range. In all cases the study unit would be capable of rapid response to load demand.

Level 1 recommendations, which are primarily for operational ease and flexibility and require no system or equipment design changes, are redundant valves in critical bypass system areas, a flame monitoring system, enlarged computer capability for monitoring tube-metal temperature, and new burners and controls for better fuel input turndown capability. Level 2 recommendations include level 1 but also require design changes to upgrade the bypass system to the current contractor standard. Level 3 recommendations include level 1 but require extensive design changes, such as spiral furnace design and full pressure separators, including a recirculation pump, to replace the present bypass system.

These recommendations are applicable to the study unit boiler and other subcritical and supercritical boilers of similar design, depending on the utility cycling requirements for the specific unit. This project demonstrates that once-through steam generator system design options capable of satisfying the study unit cycling performance requirements are presently available.

A fourth project (with The Analytic Sciences Corp.) compared control system technology used in fossil-fuel-fired generating plants with current state-of-the-art control system technology (CS-1718). A significant finding of this study, supported by observations during the cycling tests performed under RP1266-13 and RP1034, is that when a unit is operated as a baseload plant, existing control systems have proved adequate. However, when a plant is required to operate in a cycling mode, existing control systems have been found to be inefficient and unreliable—adequate only with operator intervention and manual control.

The fifth project (with Power Dynamics, Inc.), which is still under way, assesses turbine bypass systems (RP1878). The overall objectives are to identify, classify, and assess the relative benefits and costs associated with turbine bypass systems and to develop technical and economic methods for evaluating their installation and use in new and retrofit situations. Specific objectives are the following.

- Assess the various classes of current fossil units for cyclic operating parameters, such as the units' ability to sustain a full or partial load rejection without tripping, the time required to return to full load following a trip, and the time required to reach full load after an overnight or weekend shutdown

- Assess the technical and economic benefits of achieving better load rejection capability, shorter restart and reloading times, fast-valving capability, and reduced hard-particle erosion

- Identify and assess various means of achieving improved performance through the application of partial- and full-capacity bypass systems

- Provide sound guidelines for utility economic trade-off studies of the application of turbine bypass systems

This work will result in an economic assessment guideline utilities can use to analyze their individual economic benefit and cost factors. *Project Managers: John Parkes and John Dimmer*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DISTRIBUTION

Electrical interference on power lines

Distribution and transmission lines are designed to conduct electric power at 60 Hz. These lines also conduct and radiate harmonics and other electrical noise that are generated by both utility and customer equipment. Such harmonics and noise are potential sources of interference with digital communications and control systems. Typical victims of interference are transmission and distribution line carrier systems, control and switching equipment, and substation SCADA equipment. In addition, this radiation is an interference to radio and television receivers, military radar, railroad control systems, communication receivers, and ship and airborne navigational systems. A project funded by EPRI (RP2017) should provide new baseline data to both utilities and manufacturers that can be used as guidelines for designing electrical and electronic equipment to minimize harmonics and noise. Interference measurements will be made on 100 feeders located across 10 utility systems in the United States. *Project Manager: William Blair*

Impact of lightning surges on distribution transformers

A project started in 1980 to determine why properly protected distribution transformers fail during lightning storms is now approaching an end (RP1532). The objective of the research was to determine under what conditions a surge arrester would not protect a transformer that was in good condition and to find out how and why transformer insulation might deteriorate to the point where it could no longer be protected by conventional practice. Consequently, experiments were performed to determine the following.

▫ The voltage distribution in primary and secondary coils

▫ The influence of turn and layer geometric relationships to impulse strength, and how the impulse strength is affected by contaminants in the oil

▫ The degradation of insulation dielectric strength from load cycling, age, and stress

These investigations were performed on either full-scale coils or special model coils designed for the purpose, but emphasis was placed on simulating real-world conditions. Impulse studies, for example, were performed with a variety of waveshapes that could be expected to occur naturally—not simply with the standard waveshape.

The results of the above studies played a key role in selecting test parameters for subsequent experiments with full-scale transformers. These results pointed to the range of worst-case conditions, thereby reducing the number of inherently expensive full-scale tests required. Full-scale transformers were used in impulse tests to confirm findings of the model tests on voltage distribution in the coils and on aging effects. The protective characteristics of surge arresters discharging nonstandard waves were also investigated.

All the work in this project did not start at ground zero; a literature search disclosed considerable past work on the subjects of voltage distribution, aging and life characteristics, and the results of field investigations. With such results as starting points, we were able to use our resources to expand our knowledge without duplicating past efforts.

One of the most significant findings was that modest surges entering the secondary winding of some transformers can induce high-magnitude voltages in the center of the primary winding that the high-side surge arrester cannot protect against. This phenomenon was described in a paper presented at the 1982 IEEE Winter Power Meeting.

For further insight into the anomalous failure of transformers, a number of utilities saved and dismantled transformers that failed during storms. Their reports are still being categorized, and the results will be included in the final report. The effects of design changes that were tried in order to improve the surge characteristics of distribution transformers will also be discussed in the final report, which is expected to be published in October 1982. *Project Manager: Herbert Songster*

Tree growth control

The cost of clearing trees from electric distribution lines is a sizable portion of a utility's distribution maintenance budget. Substantial savings in tree trimming operations are possible by extending present trimming cycles by one to three years. Since 1974 the U.S. Department of Agriculture's Nursery Crops Research Laboratory at Delaware, Ohio, has been working under an eight-year agreement with EPRI to develop effective woody species growth regulators to retard growth (RP214). Encouraged, guided, and assisted by a growing nucleus of interested utility foresters, the researchers have established a good basis for commercialization and effective application of tree growth retardant chemicals.

Specific accomplishments during the course of this project are fundamental to meeting industry objectives.

▫ A lightweight portable injection system has been developed to deliver an exact amount of chemical growth retardant at each injection point.

▫ EPA supplemental registration labels have been obtained to inject Slo-Gro, Royal Slo-Gro, and Atrinal into trees. (Specific tree species and dosages are listed for each.)

▫ Field trials have demonstrated that tree regrowth following trimming can be significantly reduced by trunk injection of the growth control chemicals.

▫ Experimental procedures that can be used by utility foresters for evaluating the regrowth of species not yet listed have been established.

□ Line-clearing contractors have been involved in the research process and the field trials. Four such companies will offer their services to those utilities wanting to apply this technology on their systems.

Over the past few years, particularly over the last four years, a growing number of utility foresters and tree service company representatives have attended EPRI's annual project review meetings. As a result, new participants joined the field experimental trials, and in the two years since the supplemental registration of the chemicals, a number have expanded their use. At a final review meeting held March 17–18, 1982, representatives from 17 utilities, 7 line-clearing contractors, and 3 chemical companies participated in an overall review of the project. Their desire to proceed on a commercial scope with application of this technology was evident: Virtually all are willing to perform the experimental work necessary to expand the list of species that can be effectively controlled.

Interim Report EL-112 is available, covering the first five years of this work. A final report will be available in the fall of 1982. *Project Manager: Robert Tackaberry*

Wood pole decay

Obtaining the longest possible service life from wood poles is of considerable interest to the utility industry. A project that was completed in 1980 by Oregon State University's Forest Research Laboratory developed an effective means of treating in-service poles with the fumigants Vapam and chloropicrin (RP212). During that project, internal decay was arrested in Douglas fir and western red cedar poles, and reinfestation was prevented for 10 years. Following the completion of RP212, EPRI initiated a project to demonstrate the effectiveness of these fumigants in southern pine poles (RP1471).

Investigators at the College of Environmental Science and Forestry, State University of New York at Syracuse, established the following experimental procedures to accomplish the objectives set by EPRI.

□ Identify the associated fungi and determine their toxicant sensitivities, decay capacities, roles, and decay patterns in 33 poles located on Western Electric Co.'s pole farm. These poles represent a wide range of years in service and were treated with penta or creosote.

□ Compare several methods for detecting decay in poles.

□ Determine the effectiveness of Vapam and chloropicrin to arrest decay development.

□ Identify the major decay fungi associated with various decay types and patterns in a large regional sample of treated pine poles in service in the eastern United States.

Work under the first objective has been completed. As many as 255 fungi were found in the Western Electric group of poles. They have been identified and classified into three groups: hymenomycetous decayers (10 species), soft rotters (9 species), and microfungi (15 species). An analysis of when and where these fungi appear in the sample poles indicates that both outside-in and inside-out invasion patterns occur. Toxicant and fumigant sensitivity tests have been conducted on the major pole-inhabiting fungi. It is significant that some soft rotters are more tolerant to creosote, penta, Vapam, and chloropicrin than are the hymenomycetous decayers. Laboratory data and anatomical studies indicate that soft rot fungi are commonly present in pine poles and that their actual roles and the damage they cause may be more important than previously thought. This needs further assessment.

Tests under the second objective, comparing the decay detection methods of electric resistance, sonic probe, needle penetration, and X-ray, have been completed. Capabilities and limitations of each have been detailed.

Field tests on the effectiveness of the fumigants (Vapam and chloropicrin) to control various stages of decay have been established under the third objective. Based on one-year (chloropicrin) and two-year (Vapam) reisolation data, both compounds initially kill all the fungi in poles. Additional time is needed to determine their respective protective periods and any fungal reinvasion patterns.

Isolations from pole samples obtained from a variety of utilities throughout the southern pine pole usage area are continuing. Many of the same decay fungi found in the Western Electric sampling are appearing.

No such detailed investigations and analyses of the fungi population in poles were made prior to this project. The study of the reinvasion patterns will establish the time and position of each segment of the ultimate total population as it reappears. Consistent results in this study will permit scheduling a time to re-treat poles before total fungal population reappears. *Project Manager: Robert Tackaberry*

TRANSMISSION SUBSTATIONS

EHV current transducer

Under EPRI sponsorship a digital-based EHV electronic current transducer (ECT) has been developed by Westinghouse Electric Corp. (RP560). The target specification for the transducer was to meet metering, relaying, and fault-recording requirements with one unit. The frequency response, specified at 10 kHz minimum, should be adequate for future current limiter control systems and ultrahigh-speed relays as well. Digital techniques were specified for the conversion and signal transmission system of the ECT in order to gain experience with a design that could be directly interfaced with future digital protective relays. Fiber-optic links were specified for the communication system.

When last reported (*EPRI Journal,* April 1980, p. 48), the ECT was operating in a Bonneville Power Administration 500-kV substation, having been installed in August 1978. BPA ended collection of field data in July 1981, and the ECT itself was removed from service in January 1982. Removal of the ECT was performed by a normal utility crew, taking only minimal precautions. No problems were encountered and no optical fibers were damaged.

Since the last report, one of the 300-m optical fibers that ran from the substation yard to the control house failed. The failure took the form of slow degradation in light throughout, such as might result from propagation of a crack in the optical fiber. The cable has been returned to the manufacturer to determine the actual cause of failure. Another latent design defect was also discovered and corrected: It was found that inadequate filtering on the optical receiver power supply generated false parity error counts on the fiber-optic link. Thus, the actual parity error rate may be lower than previously reported.

One of the redundant encoder units at line potential also failed just prior to removal of the ECT from service. Later inspection revealed a failed analog-to-digital converter and power supply regulation transistor. This is the first encoder failure in six and a half years, which matches the five-year reliability prediction for the encoder unit very well.

Within the accuracy of the data acquisition system used by BPA, no degradation has been detected in the accuracy of the ECT. BPA is considering a laboratory test on the operational half of the device.

The experience gained in this project has shown that fiber optics are quite feasible for use in substation environments. The state of the art in this field has also advanced significantly since this system was designed. Today's fiber-optic system can therefore be expected to perform even better than the tested system did. *Project Manager: Stig Nilsson*

Reduction of fault duration

The problem of limiting fault current is very difficult if action is to be initiated during the first loop of fault current. Not only is the time available to sense the fault very short but the task of inserting a suitable impedance before the peak of the first current loop is extremely difficult and costly.

If the first major loop of fault current could be tolerated, however, limiting the remaining fault current would be relatively easy. This can be done in one of two ways. One is to install a high-speed switch in parallel with a current-limiting reactor so that when a fault occurs, opening the switch will insert the reactor at the first current zero and limit the current. Another way is to use high-speed conventional breakers in substation power source circuits; when a fault occurs, high-speed sequential tripping can be used to remove sufficient source circuits to reduce the fault current to a level that the protected breakers can handle.

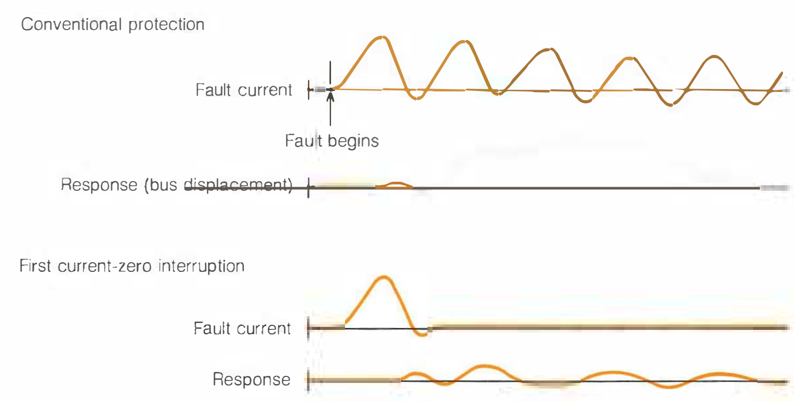
Either of these current-limiting schemes will subject the substation equipment to one major loop of fault current before the current is limited. This made it necessary to determine the effects of the reduced fault duration on the transmission substation components, and in 1979 EPRI let a contract to Stanford University to study this problem (RP1498).

A series of workshops were conducted to gather information from industry experts who represented the electrical equipment manufacturers and the utilities. A review of the literature was also a part of the effort. The workshops permitted selected electrical equipment design experts to describe how equipment behaves when subjected to high-magnitude fault currents and to assess the expected behavior when faults are of short duration.

The utility representatives came from utilities that have a strong interest in current limiting, and they provided fault data to help determine the probability, frequency of occurrence, and severity of certain faults. They also suggested the current levels and voltages at which current limiting would be beneficial, discussed the acceptability of non-disabling damage, and recommended the use of special operating procedures.

Analysis of the information provided some very encouraging results. Some equipment, such as disconnects and bus structures, can be expected to benefit sufficiently from reduced fault duration to permit an increase in tolerable fault current levels (i.e., until the fault current passes through the first current zero, Figure 1). Power transformers, however, will need careful consideration because the method of establishing momentary ratings has changed and older units may be marginally rated. However, in installations where bus fault currents are increased because of load-side paralleling, the transformer through-fault current is generally reduced, so these current-limiting schemes may be safely applied.

Figure 1 EPRI's studies show that by limiting the duration of a severe fault to a single major loop, it is likely that most apparatus can accommodate the increased fault with no disabling damage. Illustrated is a plot of bus response.



The power circuit breaker was of greatest concern. How would the contact structures behave in the closed position when subjected to the excessive fault current? Analytic procedures were developed to establish the magnitude of current required to pop breaker contacts, but some testing was needed to verify these values. Circuit breaker interrupters, representing six different contact structures, were provided by cooperating utilities and tested in the closed position at currents up to 200% of the peak momentary rating. As had been predicted by industry experts and computer analysis, finger-cluster-type contacts performed well, while butt-type contacts popped at their rating. There were no cases of contact welding, and even on contacts that popped, damage from the test series was moderate and not disabling. Tests were not made to establish the behavior of breakers being closed into a fault above their rating because it is believed that operating procedures can be established to avoid this possibility.

The study of industry fault current data reveals that the probability of the worst-case fault occurring is so low that the likelihood of damage to the equipment when these schemes are used is very small.

The equipment necessary to provide the benefits of fault-limiting protection can be developed with today's technology. A high-speed or one-cycle breaker is adequate for this service. It is significant that such a device can have the reliability required for fault-current-limiting applications. The final report on this project will provide considerable background information and serve as a guide in making these applications. *Program Manager: Narain G. Hingorani*

Testing to detect PCBs in oil

The utility industry has about 20 million oil-filled transformers that need to be tested to determine if the oil is contaminated with PCB. To test every transformer suspected to be contaminated with PCB could represent over a billion dollars in cost to the industry. Among the different approaches being developed by EPRI to help reduce this cost, a screening method has emerged through a research project with General Electric Co. and Salt River Project (RP1713).

A commercially available desktop instrument, Model MESA 200, manufactured by Horiba Instrument Co., can readily measure chlorine content in an oil sample. This simple and inexpensive test method can be used to screen out any oil samples that have a low enough chlorine content to be considered free from PCB contamination. The oil samples with significant (20–30 ppm) chlorine and above, however, must be retested on a conventional electron-capture gas chromatograph to determine the actual PCB content. Not all oil samples with a high chlorine reading necessarily have a PCB contamination problem. For example, a high chlorine content can be detected if the oil sample contains other contaminants such as chlorinated solvents or trichlorobenzene.

In an average eight-hour workday, from 80 to 125 oil samples can be tested with this instrument. Other than pouring a small quantity (1–2 cc) of oil into a sampling cup and loading the cup into the instrument, no special sample preparation is required. The instrument, after a two- or five-minute test sequence, prints out the chlorine content on a paper tape and is then ready for the next sample. While an oil sample is under test, the operator can be preparing the next sample cup and logging in the chlorine reading on the preceding test. The operation does not require any special skill, and an average technician or lineman can be expected to conduct the tests.

To assess the instrument's performance and its value as a screening tool, EPRI sponsored preliminary tests at General Electric to establish a correlation between chlorine readings and possible PCB content; the instrument was then mounted in a station wagon and has been evaluated by eight different utilities located across the country (Figure 2). Salt River Project has assumed the role of lead utility and has been the focal point of this field evaluation.

In general, our experience shows that this instrument is very easy to use and offers an extremely cost-effective screening method. Only two utilities have arrived at a marginal economic justification, but in these cases the screening test called for a retest because of excessive contamination from either chlorinated solvents or too much sulfur in the transformer oils under test. Chlorinated solvents give a positive error, resulting in excessive retesting, and high sulfur in oil requires dilution and retest, shifting the economic equation. As stated earlier, however, the overall experience has been very favorable, showing good economic justification for any utility having a large number of oil samples in need of PCB analysis. Also, as the test program does not require special expertise in chemistry, most people on the utility payroll can operate this instrument. To illustrate the experience, a summary of a report prepared by James Henderson of the Arkansas River Power Authority (ARPA) follows.

The Horiba instrument was transported for hundreds of miles by station wagon over public roads to six different cities with elevations ranging from 6185 to 3622 ft. During transportation, the Horiba instrument was subjected to large fluctuations in ambient temperatures. The calibration of the instrument appeared to be unaffected by changes in elevation, fluctuations in ambient temperatures (which ranged from below freezing to room temperature), or by the normal jars and jolts associated with transportation in a station wagon. The Horiba instrument might be characterized as a rugged instrument, capable of withstanding the normal rigors of transportation without periodic recalibration.

ARPA's experience indicated that almost anyone could operate the instrument. The instrument operators ranged from people with very limited educational backgrounds to engineers with college degrees. Since in many locations the instrument was used 24 hours around the clock, approximately two dozen people operated the Horiba instrument.

Most of the oil samples ARPA had tested were taken from pole-mounted distribution transformers, requiring a bucket truck with a three-man crew. By using a systematic block-by-block approach, samples could be drawn in less than 10 minutes, with only a general notice given to the public stating that power would be interrupted. Under these circumstances, the cost of taking a sample was estimated to be $12, assuming a bank of three pole-mounted transformers. A more normal approach would have required giving specific notice to each customer, resulting in much longer travel time.

Repeated testing of the same oil samples with the Horiba instrument yielded consistent results. This was true when the tests were run for 30 seconds. Increasing the length of analysis time often reduced the standard deviation but usually did not significantly affect the chlorine count. Generally, increasing the length of analysis time yielded more consistent results.

The Horiba instrument is capable of giving fast, accurate, and useful results. The instrument is extremely simple to set up and operate. The instrument was effective in determining that approximately 62% of the oil samples contained less than 50 ppm chlorine.

Henderson concludes by saying, "In my opinion, use of the Horiba instrument could be economically justified by any utility having a large number of oil samples." *Project Manager: Vasu Tahiliani*

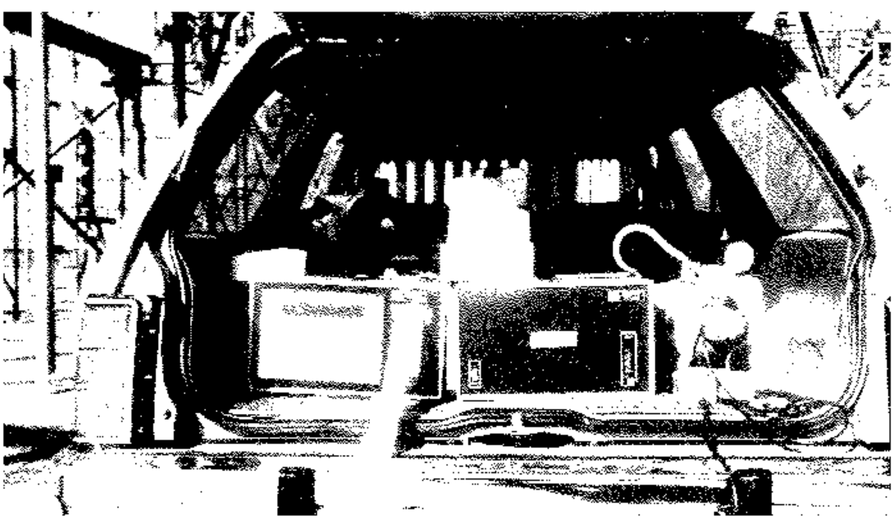


Figure 2 Mounted in the rear of a station wagon, the Horiba MESA 200 chlorine content analyzer has survived transport over hundreds of miles of road, elevations above 6000 ft, and wide fluctuations in temperature. Its simplicity offers an extremely cost-effective screening test of PCB content in power equipment oil insulation.

Paper insulation for transformers

The development of improved, yet economically effective, electrical insulation for use in transformers represents a formidable challenge to the transformer industry. One reason is that the property requirements for the insulation differ, depending on the voltage rating and the specific application within the transformer. As described in an earlier *EPRI Journal* article (March 1981, p. 47), modified papers have been used in transformers in the past, but manufacturers have not performed significant R&D on improved papers in recent years. A need exists not only to further upgrade thermal properties (so the insulation can withstand hot spot temperatures) but to impart superior dimensional stability, improve mechanical strength, and reduce the insulation's tendency to absorb moisture. Such improvements must be achieved without degrading the material's dielectric properties. EPRI has brought together a team consisting of a transformer manufacturer (McGraw-Edison Co.), a paper manufacturer (Riegel Products Co.), and the paper research institute (Institute for Paper Chemistry) to focus on this area (RP1718).

The Institute for Paper Chemistry has performed extensive R&D on papers, but very little R&D has been performed for transformer applications. To this end, the institute will conduct a literature survey of R&D by others on the thermal and electrical properties of papers.

McGraw-Edison has started to focus on modification of kraft papers, employing commercially available materials; if successful, Riegel will evaluate processing variables in the papermaking process. Later in 1982, specific modified papers will be selected for combined electric and thermal testing. *Project Manager: Bruce Bernstein*

ROTATING ELECTRICAL MACHINERY

Electrochemical machining

The trend toward the use of tougher turbine and generator rotor materials has led to significant increases in residual machining stress; this, in turn, has prevented manufacturers from obtaining the desired rotor surface finish because of the difficulty in blending successive cuts in the milling process. This is evidenced by such problems as tears, metallurgical transformation at the surface, and galling of the rotor. Tougher rotor materials also cause premature cutter failures during the machining operations. Fortunately, the development of electrochemical machining (ECM) allows for machining both today's rotor material and the tougher materials that will be used on advanced generator designs; it also offers undisturbed material and surface properties, more uniform rotor slots, the ability to machine to close tolerances, and a method to machine more-complex slot geometries. In aggregate, these advantages could expand the design flexibility of rotor-slot geometry and offer the potential for improved generator performance.

EPRI therefore sponsored a project to define and evaluate a rotor-slot machining technique for machining tougher material without causing surface stress (RP1823). A secondary goal of this project was to enhance the quality of machining the more conventional rotor alloys and to increase the flexibility of rotor-slot design. Addressed as a part of this project was a detailed study of past ECM development, particularly from the standpoint of problems encountered with the creation of surface irregularities.

This 18-month project is now complete and has demonstrated the feasibility of machining complex rotor slots in conventional turbine generator materials, such as Ni-Mo-V (ASTM 469-Class 5) and Ni-Cr-Mo-V (ASTM 470-Class 7), and in an advanced metallurgical alloy, Inconel 706. Metallurgical examination and mechanical test results of materials machined by ECM compare favorably with those for materials finished by conventional machining techniques. The process of ECM also results in shorter elapsed times to finish-machine a rotor slot.

Tool costs are at a minimum because no ECM tools are consumed in the machining process. ECM offers unique capabilities for overcoming machining limitations not only for the present generation of rotor materials but especially for future rotor materials. The ECM technique offers the possibility of producing complex, finished rotor-slot geometries that can be effectively applied to the electrical and mechanical design of rotors.

Before this technology can be introduced to the manufacturing environment, however, it will be necessary to evaluate its use in each individual situation. The results of this project provide the necessary background, machining experience, and reference for the manufacturing community to effectively evaluate the merits of ECM before it is used on a widespread basis. *Project Manager: James S. Edmonds*

Superconducting generator

The project to develop and build a 300-MVA superconducting generator that was started in 1979 is moving along as expected, and a prototype unit should be shipped and installed during 1985. This unit is designed to be driven by an existing steam turbine, and the host utility, the Tennessee Valley Authority, expects to install the unit for continuous operation in its Gallatin plant. The benefits attributed to this innovative design were thoroughly described in the March 1980 issue of the *EPRI Journal*, p. 47, (RP1473).

During the two years of intensive engineering design work and concept testing that have taken place since the beginning of the project, the feasibility of building a highly reliable superconducting generator has been confirmed and the design configuration and specifications are complete (Figure 3).

Three significant accomplishments mark the progress of this project thus far.

- Successful completion of the heat transfer experiment produced the required helium characteristic data that were previously unavailable from other industry research.

- The largest melt of the superalloy Inconel 706 has produced two acceptable ingots, one of which was successfully extruded for high-strength rotor components and several experiments to be conducted in 1982.

- An improved stator air gap winding design has been developed to take full advantage of

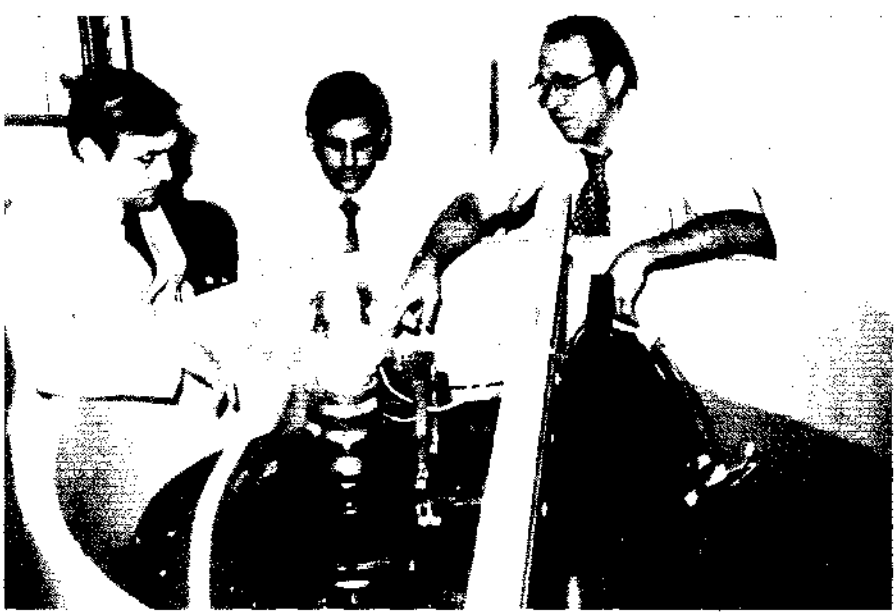
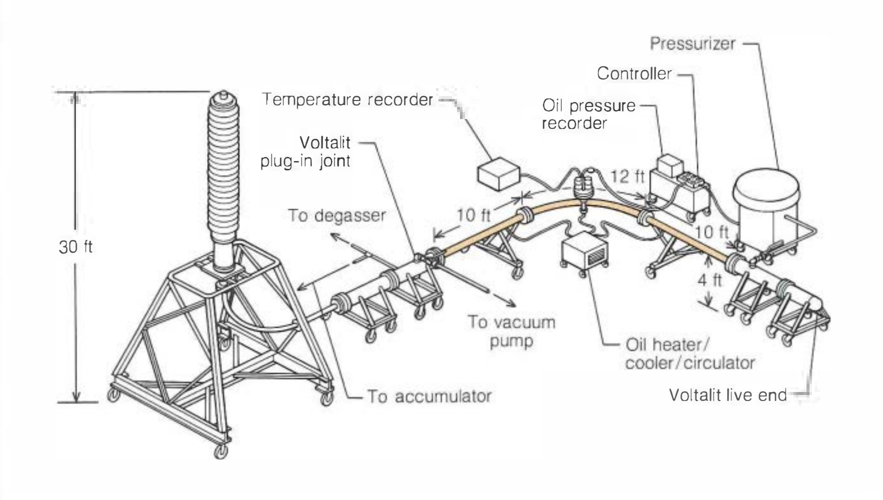


Figure 3 The final design of the superconducting generator rotor was confirmed by the successful operation of the heat transfer experiment.

Figure 4 Modular test setup for 32-ft active section of any HPOF cable rated 138–345 kV, now installed at the Phelps Dodge EHV laboratory.



the spiral pancake geometry and to provide a more reliable configuration than is currently in use on conventional generators.

The project is now in the early stages of manufacturing, and continued successful development should result in a reliable machine capable of passing rigorous factory and field tests and, of course, continuous power plant operation. *Project Manager: James S. Edmonds*

UNDERGROUND TRANSMISSION

Cable breakdown study

Present-day high-pressure oil-filled (HPOF) pipe-type cable systems rated 138–345 kV are considered to be highly reliable, yet breakdown data under ac impulse and switching surge conditions are either scant or nonexistent. Extruded dielectric cable systems in the 115–138-kV class, with less certain reliability and history, have a similar lack of breakdown data.

This dearth of data exists despite the fact that industry specification groups require this information in order to write intelligent and less conservative standards. The lack of statistically valid breakdown data does not result from industry lethargy, but largely from the cost of testing. For example, a single breakdown point on EHV cable, obtained by using conventional techniques and equipment in an EHV testing laboratory, will cost $30,000 to $40,000.

What are the proper design levels (i.e., insulation thicknesses) for cable? The answer can only be obtained by having statistically valid breakdown data. To acquire these data, EPRI and Empire State Electric Energy Research Corp. (Eseerco) have cofunded a study on the breakdown of HPOF and extruded dielectric cable, with Underground Systems, Inc., as prime contractor (RP7879-1). Most testing will take place at Phelps Dodge Cable & Wire Co.'s EHV laboratory in Yonkers, New York.

A unique modular test setup for HPOF cables, using a plug-in active sample via a Voltalit joint, live end, and permanent riser cable and terminator, reduces testing cost and time considerably (Figure 4). Three such setups have been fabricated, allowing a production line concept of sample installation, treatment, conditioning, test, and removal.

The scope of the project entails the definition of the breakdown test program and sample characterization tests; evaluation and purchase of improved modular test equipment; performance of all breakdown tests, sample characterization tests, and sample dissections after breakdown; and reporting of results. Approximately 150 breakdown tests are planned in this 3½-year project. A comprehensive analysis and correlation of the acquired data can be a follow-on effort. *Project Manager: John Shimshock*

POWER SYSTEM PLANNING AND OPERATIONS

Bulk transmission system reliability evaluation

The reliability level of a power system has a direct impact on the quality of service that customers receive and the rates they pay. Electric utilities, therefore, are under pressure to evaluate system reliability in terms of the trade-off between cost and associated benefits.

A two-year project with Power Technologies, Inc., recently completed, developed a probabilistic method to assess bulk transmission system steady-state reliability (RP1530). The contractor developed advanced mathematical models for computing reliability indexes that take into account frequency, duration of power interruptions, and amount of load not served.

The models and solution methods developed in this project enable a utility to compute the quantitative system reliability, including consideration of such system problems as circuit overloads, abnormal voltages, and system separation.

The contractor developed a prototype computer program capable of computing reliability indexes for systems with up to 150 buses. Work is under way in a new project to expand this computer program to 1500 buses. The project final report and the program documentation should be ready for publication later this year. *Project Manager: Neal J. Balu*

Optimization of VAR sources in system planning

VAR optimization is concerned with the location, control, size, and type of reactive power sources installed throughout an electric utility's system so that an acceptable voltage level can be maintained under all operating conditions. A number of methods have been proposed in the past for VAR optimization, but serious shortcomings have prevented them from fully exploiting the VAR and voltage control capabilities of currently available devices; further, existing methods do not have the capability to compute solutions for large-scale (1500 buses or more) utility systems.

A 20-month project with Scientific Systems, Inc., initiated in November 1981, focuses on the development of advanced optimization methods for VAR allocation in large-scale utility systems (RP2109). The methods should be suitable for both system planning applications and the voltage control requirements of system operations.

A prototype computer program incorporating the advanced optimization methods will also be developed as part of this project. The methods and the prototype program will be tested and validated by analyzing the performance of representative large-scale utility systems.

The prototype computer program should be completed by August 1983. *Project Manager: Neal J. Balu*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

SURE FINDINGS AND CONCLUSIONS

Seven years after planning work began, EPRI's $8 million Sulfate Regional Experiment (SURE) has provided an exceptionally clear picture of the day-by-day variation of concentrations of suspended sulfate particles over the northeastern United States. The major findings and implications of this research project are summarized here. Detailed results are presented in several available or forthcoming EPRI reports (EA-1900 through EA-1914).

The original impetus for SURE came from two propositions advanced by EPA in the early 1970s: (1) airborne concentrations of acidic sulfate particles observed during air pollution episodes produce significant health effects; and (2) elevated-sulfate episodes are associated with sulfur dioxide (SO_2) emissions over large regions and with multiple-day, long-range atmospheric transport.

If verified, these propositions could have led quite naturally to regional, multiple-source control of SO_2 emissions. As the single largest emitter of SO_2, the U.S. electric power industry had a very considerable stake in this situation. Thus, through EPRI, the industry initiated the SURE project with the goal of describing regional nonurban SO_2 and sulfate (SO_4^{--}) distributions more completely and precisely than the data available in 1975 permitted. A reevaluation of the Community Health and Environmental Surveillance System (CHESS) data on which the EPA health effects assessments had been based was also undertaken (EA-450).

SURE was designed to investigate the behavior of airborne sulfur oxides and associated substances over the greater northeastern United States. The study area (Figure 1) extended from the Mississippi River to the Atlantic seaboard and from mid-Alabama to southeastern Canada, an area approximately 2400 by 1000 km.

An examination of the few data available before 1974 led to the speculation that pollution from sulfates in the greater northeastern United States is regional in nature. The concept of regional air pollution applies to situations of intensified pollution covering distances of 1000 km and lasting more than two days. Because there are many SO_2 sources in the Northeast, the distribution of atmospheric sulfur oxides could be the result of localized accumulation; it could also involve the transport of pollution over great distances. Because systematic measurements of sulfur oxides and associated substances were limited, it was not possible to determine the extent of regional-scale phenomena and appropriate control options.

In preparation for the full-scale SURE project, historical air quality observations were examined to determine the apparent pollution climatology of the SURE region and the temporal and spatial distribution of all emission sources in the region. This design study indicated that certain meteorologic conditions were most conducive to the buildup of atmospheric sulfates. It also indicated that during periods of sulfate buildup over an area stretching from the Ohio River valley to the Atlantic seaboard, the maximum sulfate concentrations occurred 100–300 km northeast (or downwind) of the major SO_2 emission areas. An analysis of data from other regions in the United States indicated zones of maximum influence that were similar in scale. The design study also found that the highest atmospheric sulfate concentrations occurred during a period of several days in summer over areas influenced by marine tropical air masses. SURE was implemented to extend the limited data base and then use the data to address various issues about the occurrence and origins of atmospheric sulfur oxides.

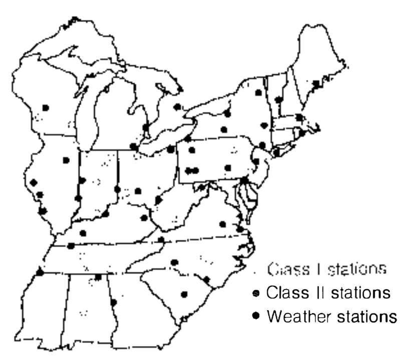


Figure 1 The SURE region, showing Class I and Class II monitoring stations and National Weather Service stations. The nine Class I stations were instrumented to measure SO_2, ozone, nitrogen oxides, hydrocarbons, and total suspended particles; they were operated continuously from July 1977 through October 1978. The 45 Class II stations, which measured SO_2 and particulates only, were operated for six 30-day periods during the project. The weather stations provided relevant meteorologic data.

Project activities

To accomplish these objectives, three major activities were undertaken and coordinated in the SURE project. First, a 54-station network of pollutant monitors was established over the northeastern United States (Figure 1). This network was operated from July 1977 through October 1978. The data acquired were subjected to extensive error checks and precision analysis. They were then archived for analysis and for use in model development. In addition, two to five aircraft were flown during selected periods to measure pollutant distributions from near the ground to an altitude of 3 km (10,000 ft) above mean sea level. All relevant meteorologic data were acquired from the National Weather Service.

Second, an updated source inventory of SO_2, nitrogen oxides, total emitted particles, and three reactivity classes of hydrocarbons was prepared on the basis of known source distributions (area and point). In addition, hourly estimates of SO_2 emissions from all power plants with a rated capacity greater than 50 MW were made for six selected 30-day periods during 1977–1978.

Third, an analysis and regional modeling program was conducted to interpret the data acquired by SURE. Major efforts were devoted to meteorologic and statistical analyses of the data and to developing an improved regional air quality model.

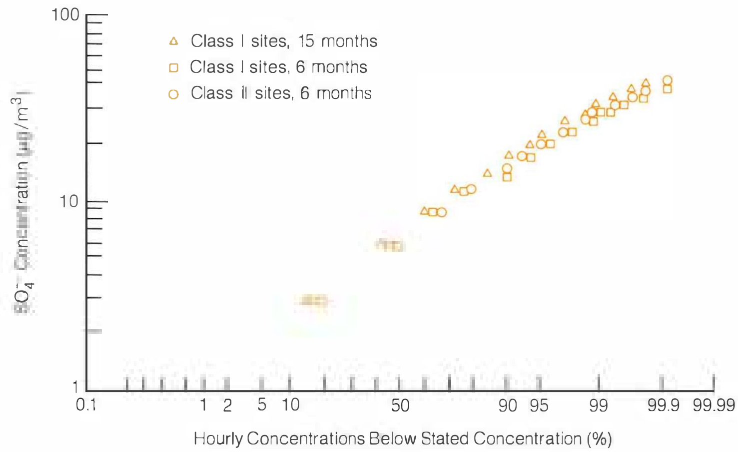
As a result of these activities, the SURE project acquired a data base of approximately 30 million entries that reflects the daily concentrations of primary (SO_2) and secondary (SO_4^{--}) pollutants over an area of 2.4 million km² (890,000 mi²). Further, the accuracy and precision of the aeromatic data base have been carefully determined.

Major SURE results

The most valuable result of SURE to date is the provision of an accurate, reliable, and detailed description of the day-by-day variation of sulfur compound concentrations over the northeastern United States. The history of sulfur emissions and the resultant exposures to SO_2 and sulfates in nonurban areas is now known in unprecedented detail and with unprecedented reliability. The degree of detail possible with these data is shown in Figure 2, which plots the frequency with which any given value of SO_4^{--} concentration was exceeded during the SURE period. Data indicating the chronological sequence of episodic maximum SO_4^{--} levels and background levels, coupled with measurements of SO_2 source variability and meteorologic processes, enable the assessment of sulfate exposure and causes of sulfate formation. These data reveal that sulfate levels were considerably lower than had been expected. As shown in Figure 2, the level of 25 $\mu g/m^3$ was exceeded less than 5% of the time.

A second major result of SURE is the demonstration of a clear geographic association between sulfate concentrations and major source areas of SO_2. Both the day-by-day patterns of sulfate concentration and the patterns during elevated-sulfate episodes show this association unmistakably. These patterns also indicate, but do not define exactly, a zone of influence for major SO_2 source areas. This zone normally extends 100–300 km downwind but may on rare occasions extend beyond 500 km. The primary evidence for restricted zones of influence is derived from statistical analyses of the SURE data. However, a graphic representation of the geographic association between major SO_2 source areas and elevated SO_4^{--} concentrations is achieved by plotting SO_4^{--} concentrations exceeded 10% of the time (Figure 3). The pattern of elevated

Figure 2 Sulfate concentrations (24-hour average) measured during SURE and their frequency. The 15-month data are for August 1977–October 1978. The six-month data are for August and October 1977 and January, April, July, and October 1978 (i.e., one month of each season during SURE). As shown here, concentrations above 25 $\mu g/m^3$ occurred very infrequently.



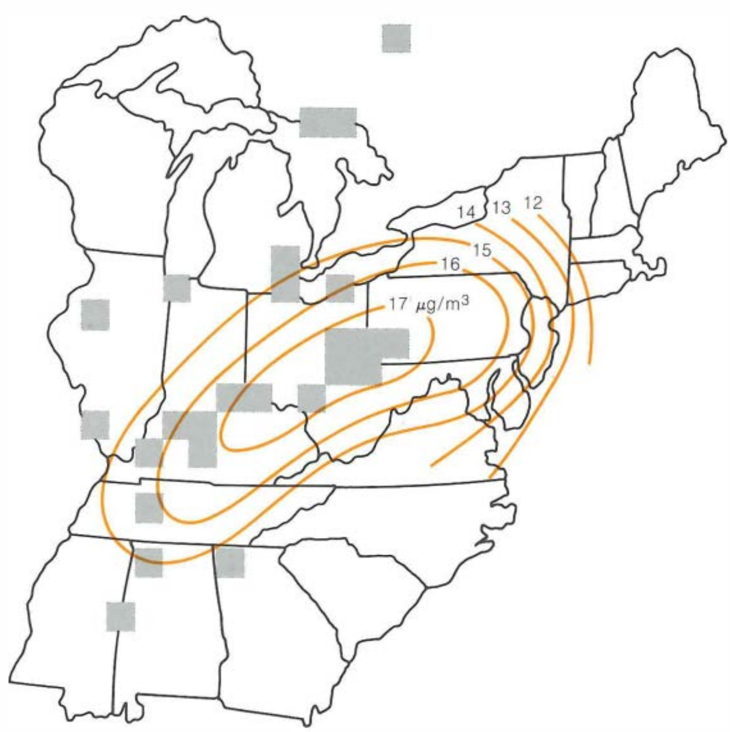


Figure 3 Elevated sulfate concentrations and major SO_2 source areas. The colored lines demarcate areas in which the 24-hour average sulfate concentration (given in $\mu g/m^3$) exceeded the indicated value 10% of the time during SURE. The shaded boxes indicate areas in which SO_2 emissions for summer 1977 exceeded 1000 Mt/d.

levels clearly surrounds major SO_2 source areas in the Ohio River basin.

It is very tempting to dwell on this geographic association between SO_2 sources and elevated sulfate concentrations and conclude that reductions in SO_2 emissions will mitigate sulfate exposure, should that be required. However, such a conclusion would be premature and could lead to ineffective control requirements. Elevated sulfate levels are associated primarily with weather conditions and pollutant mixes conducive to photochemical activity, and several of the pollutants involved (e.g., hydrocarbons) emanate from sources other than power plants. It is conceivable that the total conversion of SO_2 to sulfates is determined by the oxidant levels established through photochemical reactions, not by the total SO_2 present. Because the photochemical production of oxidants is independent of SO_2 concentrations, the reduction of SO_2 loadings alone may be ineffective in lowering sulfate levels. Thus the question is whether it would be more cost-effective to control those pollutants that play a key role in establishing oxidant levels. Further research is required to answer this question.

A third result of the SURE project is the demonstration of the level of accuracy and reliability that can be expected from the current generation of regional air quality models. In verifying the SURAD model against measured three-hour average sulfate concentrations, for example, it was found that the model tended to overestimate the average and minimum concentrations and to underestimate the maximum concentrations; however, a majority of the calculated values fell within a factor of two of the observed values. Model calculations that consistently fall within a factor of two of the observed values and that show no systematic bias toward under- or overestimation are approaching useful limits of precision for application to regionwide assessments of air quality—for example, determining the total loading of sulfates in the lower atmosphere over the entire SURE region. These models also demonstrate some skill in differentiating interregional pollution concentrations and again are useful for determining exposures over substantial areas and longer time averages.

The current generation of regional air quality models generally fail to provide useful estimates when applied to the daily evolution of elevated-sulfate events, the problem area of greatest importance in today's regulatory climate. When the models are applied to individual events, the errors and uncertainties in their calculations exceed the expected changes in pollutant concentrations that would be associated with realistic emission control scenarios. Regional air quality models will not produce useful results for the evaluation of proposed emission control strategies until they are precise enough to differentiate reliably between realistic scenarios. Again, further research is required. SURE has set the stage for meeting that need.

Implications and future research

The highlights of the SURE findings may be summarized as follows.

- Annual average nonurban concentrations of sulfates in the northeastern United States were observed to be $\leq 8\ \mu g/m^3$, approximately one-half to three-quarters of urban sulfate levels.

- On the average, 5–10% of the SO_2 emitted in the Northeast is converted to dry (nonprecipitation) suspended sulfate particles. The balance of the sulfur is either deposited or transported out of the region.

- Episodes of elevated sulfate concentrations ($>40\ \mu g/m^3$) were observed, and the concentration patterns were clearly associated with major SO_2 source areas.

- The zones of influence of major SO_2 source areas during sulfate episodes were generally limited to 100–300 km, but on some occasions they may have exceeded 500 km.

- Major sulfate events are associated with specific meteorologic conditions (stagnation and ducting) that are readily predictable.

- The model accuracy necessary to distinguish utility contributions to ambient sulfate levels has not yet been achieved. The necessary research on model development is being continued under EPRI's Regional Air Quality Studies (RAQS).

The implications of the SURE findings are varied and complicated when considered in the context of regional air quality research and air quality management. However, a few conclusions readily emerge.

- An extensive, high-quality data base on temporal and geographic variations of SO_2 and sulfate concentrations is now available for use in assessing environmental impacts when appropriate damage functions are available.

- The association between elevated sulfate levels during pollution episodes and major SO_2 source areas is unmistakable, but the impact of selective or blanket reductions in SO_2 emissions on regional sulfate concentrations is not yet clear.

- Regional sulfate models have been advanced to the stage where the root mean square error is around 50%. These models are useful for estimating various regional impacts, but they do not yet have the accuracy and precision required for reliable estimates of air quality changes associated with realistic emission control scenarios.

- SURE has provided a solid base of information that can be extended to other regional air quality problems, such as acid precipitation and visibility impairment. However, because SURE did not address these problems directly, further specialized research is required.

SURE has made a significant and lasting contribution to our understanding of regional air quality processes, particularly as they relate to the behavior and fate of sulfur compounds. The full impact of SURE will not be known for several years, but in addition to shedding much light on the sulfate issue, it has also set the stage for expanding research into the related regional problems of nitrogen compounds, the wet and dry deposition of acidic materials, and visibility impairment. It has pointed the way to a broader understanding of regional air quality variations and their causes, an understanding that is essential to a balanced approach to regional air quality management. EPRI's continuing research in the area of regional air quality (as outlined in EA-1650-SR) is firmly grounded in the SURE project. *Project Manager: Glenn R. Hilst*

RESIDENTIAL END-USE ENERGY FORECASTING

A unique type of residential end-use energy consumption and load-forecasting model has recently been developed that integrates the major features of both the econometric approach and the engineering end-use approach to energy forecasting (RP1211). The model can be used to examine how such actions as government tax incentives and utility conservation programs affect overall residential energy consumption, as well as the consumption patterns of specific groups. Originally developed for application at the national level, the model has been modified to facilitate calibration to an arbitrary regional or utility level. This procedure is currently being demonstrated through several test cases, the first for the Northwest region in cooperation with the Pacific Northwest Utilities Conference Committee (RP1918). The model is also being used in a *study of the cost-effectiveness of utility conservation programs (RP1587).*

Forecasting methods

Methods of forecasting energy demand have increased considerably in number and complexity over the past decade in response to rising uncertainties about potential demand growth rates. These methods go beyond simple extrapolation of historical growth trends. The most commonly used approach is aggregate econometric modeling.

Aggregate econometric models for the residential sector have the advantage of being derived directly from widely accepted economic theories of consumer behavior. They are particularly useful for testing the sensitivity of energy demand growth to energy prices and income. They behave essentially as black boxes, however, predicting how much consumers adjust their energy consumption in response to changes in price and income without describing what form these adjustments take. Thus for the analysis of a number of important nonmarket factors, such as federal and state tax incentives, appliance efficiency standards, and utility conservation programs, aggregate econometric models have limited use.

The need to determine how energy consumption is affected by conservation programs targeted at specific end uses has motivated the development of end-use models of energy demand, the first being the residential model developed at Oak Ridge National Laboratory. Such models have strong appeal because they clearly associate energy consumption with specific appliance activities in fine detail. They also have major limitations, however, in that they require extensive information about projected appliance market penetration and utilization rates, and they often represent end-use energy consumption by engineering estimates rather than by actual consumption in practice.

In 1978 EPRI initiated a major project with Cambridge Systematics, Inc. (CSI), to develop a new state-of-the-art model of residential energy demand by integrating significant elements of both the econometric and engineering end-use approaches (RP1211). The model explicitly considers the major appliance end uses and projects their market penetration and energy usage rates. These projections are based on disaggregate econometric relations that are drawn from a theory of consumer choice and that are sensitive to energy costs, the technologic and performance characteristics of alternative appliances, and household attributes. The behavioral parameters of these relations are estimated statistically from household survey data. Thus the forecasting system exhibits the structural detail that is the strength of the more traditional end-use approach, while maintaining firm behavioral foundations in consumer choice theory and actual data on household decisions. In forecasting, the model simulates decisions regarding appliance choice, efficiency, and utilization for a representative sample of households.

Model structure

Information flow in the simulation model is shown in Figure 4. The model predicts three categories of energy-related decisions—appliance choices, annual energy consumption, and electricity loads—in a recursive manner. Appliance choice is dependent on housing characteristics, energy consumption is dependent on housing and appliance holdings, and electricity loads are dependent on appliance holdings and total consumption.

Appliance choices are treated explicitly in the model because of their central role in determining total household energy consumption and load patterns. The direct modeling of these investment decisions enables the evaluation of various conservation measures aimed at new housing construction, where investment choices are made.

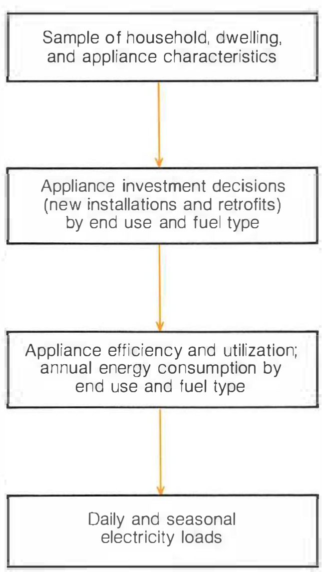


Figure 4 Information flow in the EPRI–CSI residential model, which combines econometric and engineering end-use techniques to forecast appliance choices, energy consumption, and electricity loads in the residential sector. The model can be used to evaluate the impacts of such activities as tax incentives and conservation programs on all households or on specific types of households.

The model's appliance investment component forecasts the purchase and ownership of energy-using household devices and their characteristics for six major end-use categories (space heating, water heating, air conditioning, cooking, dishwashing, and other/residual) and three fuel types (electricity, natural gas, and other fossil fuels). It also distinguishes between 29 categories of dwellings in terms of structure type, size, and age. To give an example of end-use detail, space heating is divided into electric heat pumps and fuel-specific forced-air, hydronic, and noncentral systems. The addition of appliances for other end uses, such as refrigerators and freezers, is planned.

The appliance utilization component of the simulation model forecasts appliance and building energy efficiency and annual energy consumption by major fuel and end-use categories, given the type of household and dwelling and the appliance portfolio. For all appliances, efficiency choice depends on energy prices and household and dwelling characteristics. Given efficiency, energy consumption is determined by the utilization of the appliance. Utilization rates are calculated as a function of energy prices and household and dwelling characteristics. Seasonal and daily electricity loads are calculated on the basis of annual energy consumption and appliance holdings.

A key feature of the model is the method used to derive total or average household behavior for specific population groups or for all households. Because the component behavioral equations represent individual household behavior and are typically nonlinear in the explanatory variables, an aggregation problem exists. Average values of the explanatory variables are insufficient to forecast average energy consumption. Information on the joint distribution of those variables is required. That information is provided in the model by a representative sample of households. (In utility-level applications, data necessary to characterize the sample can be obtained by typical household appliance saturation surveys.) A method of sample enumeration is then used in which each sample household's energy decisions are predicted on the basis of the model's behavioral relations and the household's characteristics. Total consumption is forecast by multiplying the individual predictions by their respective sample weights and adding the results. This microanalytic simulation method is a powerful tool that provides the capability to examine distributional as well as total impacts of such factors as conservation programs.

Model results

One type of forecast information produced by the model is shown in Table 1 for a base case run. Average electricity consumption for various categories of households (as defined by the presence or absence of major electrical end uses) is presented, as well as average electricity and energy consumption for all households. It is interesting to note that while average household energy consumption falls by 21% over the 20-year forecast period (from 130 to 103 million Btu), average household electricity consumption increases by 12% (from 9.0 to 10.1 MWh). However, an examination of the category averages shows that the increase is due almost entirely to the changing composition of households (e.g., increased penetration of central air conditioning and electric heating). Nearly all the individual categories show declines in electricity consumption, undoubtedly as a result of higher electricity prices. *Project Manager: Steven Braithwait*

FUEL PLANNING AND MANAGEMENT

In the past decade, obtaining fuel supplies for electricity generation has become increasingly complex, expensive, and uncertain. Fuel acquisition decisions have long-term implications for utility planning and have a bearing on many aspects of utility business. Among the considerations involved are electricity demand, fuel mix, plant performance, boiler design, plant siting, coal cleaning, scrubbing equipment, plant conversion, off-system power purchases, and fuel inventories. Not least is the impact on revenues and rates.

The Supply Program's research in fuel planning and management has the following objectives.

- Provide tools for improved fuel planning under uncertainty
- Develop technical information critical to the design of fuel acquisition procedures
- Promote technical information exchange among utility fuel planners and managers

The bases for these objectives are the potential payoffs to utilities in reduced fuel costs, improved fuel quality and reliability, flexibility to handle contingencies, reduced exposure to cost escalation, and improved communication with management and with regulatory commissions. A clue to the magnitude of only a small percentage in cost savings is given by the fact that utilities burned $17 billion of coal in 1980.

Four research projects initiated last year are aimed at attaining these objectives. Broadest in scope is a series of five-day workshops on applications of decision analysis to utility fuel planning and management (RP1947-1). These workshops demonstrate the usefulness of techniques of decision analysis in portraying the various consequences and risks associated with such decisions as opening a coal mine, securing oil supplies, contracting for uranium enrichment, and setting coal inventory levels. In each case, the decision maker is faced with incomplete information, uncertainties in costs and prices, many possible delays, changes in regulations, and uncertainties in electricity demand.

By sorting out the risks and uncertainties from the perspective of the techniques demonstrated in the workshop, the participants can see how seemingly intractable problems can be systematically analyzed. Opportunities where an investment to obtain more information may be worthwhile can be identified. Decision analysis is shown to be a valuable tool complementing the skills and technical information available to the utility. A casebook containing examples of decisions and the methodology will be published in 1982.

Two other research projects are directed at developing tools to address specific fuel planning problems: responding to potential coal supply shortages (RP1947-2) and determining a coal supply contract mix (RP1921).

In both these projects, decision analysis provides a means for structuring the problem and evaluating the risks and probable consequences associated with different choices. The tools are designed for utility applications, having been developed through working closely with utilities on actual decisions.

A number of utilities are presently reassessing their coal inventory levels. To assist them, an EPRI project is enhancing and transferring a coal purchasing model initially developed by Carolina Power and Light Co. (RP1947-2). This model can help utilities determine when to purchase coal in spot markets, while drawing down coal inventories during shortages; yet the CP&L model also has broader dimensions (Figure 5). Compli-

Table 1
AVERAGE HOUSEHOLD ELECTRICITY CONSUMPTION
BY TYPE OF SPACE HEATING, WATER HEATING, AND AIR CONDITIONING

	Percent of Households			Electricity Consumption (MWh)		
	1977	1985	1995	1977	1985	1995
Nonelectric space heating, nonelectric water heating, noncentral air conditioning	49	36	27	5.8	5.2	4.4
Nonelectric space heating, electric water heating, noncentral air conditioning	13	9	6	9.7	7.9	6.5
Nonelectric space heating, nonelectric water heating, central air conditioning	17	27	34	9.8	9.8	9.6
Nonelectric space heating, electric water heating, central air conditioning	5	7	7	14.1	13.0	13.3
Electric space heating, noncentral air conditioning	9	9	8	14.9	13.9	13.0
Electric space heating, central air conditioning	7	12	18	16.2	17.5	18.5
All households*				9.0	9.5	10.1

*Average energy consumption for all households (10^6 Btu): 1977, 130; 1985, 114; 1995, 103. Electricity was evaluated at 3412 Btu/kWh.

cating factors include the availability and costs of both spot market supplies and purchased power, utility regulations, and the utility's attitude toward risk. Two case study applications are being pursued with Georgia Power Co. and TVA.

At the same time, this project includes an examination of several alternative approaches for weighing the trade-offs between holding coal in inventory and facing coal shortages. These approaches and the CP&L model were reviewed at a recent workshop.

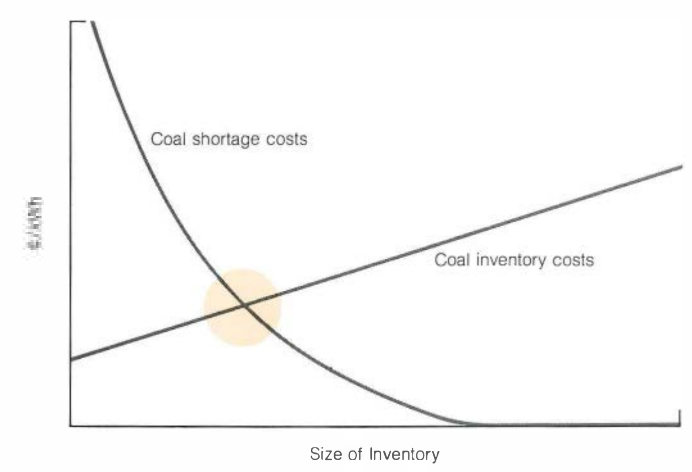
The second tool under development concerns the longer-term strategic fuel supply issue of how much coal to buy on the spot market, how much on term contracts, and how to schedule those contracts (RP1921). This decision involves weighing a host of uncertain factors (Figure 6) and is linked to the inventory policy, corporate financial considerations, coal price outlook, and many additional issues, such as the range of acceptable coal specifications, transportation costs, and the structure and details of the coal contracts.

A utility advisory group has been formed to focus this project on issues of current concern and general applicability and to aid in the selection of a utility case study as a basis for developing the planning tool. Among the utilities serving on this group are Consumers Power Co.; Houston Lighting & Power Co.; New England Power Service Co.; Pennsylvania Power & Light Co.; Southern California Edison Co.; The Southern Co.; and TVA. The Southern Co. is serving as the case study.

A fourth project examines the critical technical information needed to design a coal supply acquisition program (RP1367-3). The basis of this project was a workshop held in Austin, Texas, in November 1981 on applied coal geoscience and the electric utilities. This workshop took a broad look at the strengths and weaknesses of the technical coal supply information normally available to utilities; examined the rationale behind different utilities' approaches to obtaining the technical information required in developing their fuel strategies; and demonstrated several state-of-the-art techniques as yet not widely used but helpful in obtaining better information about coal supplies and risks.

Timely communication is important to all the work in fuel planning and management. The Supply Program issues the newsletter "Fuel Supply Analysis" to supplement the direct exchange of information at workshops and seminars. *Project Managers: Jeremy Platt and Stephen Chapel*

Figure 5 Cost trade-offs in setting coal inventory levels. The costs of coal inventories are based on some fixed-cost minimum and a relatively constant additional cost per ton; those costs are relative to the marketplace. When coal inventories are low, a utility has two choices: to purchase coal on the spot market, where prices are likely to be high, or to cover its generation shortages with costly purchased power. Costs are minimized in the vicinity of the intersection of the two curves.



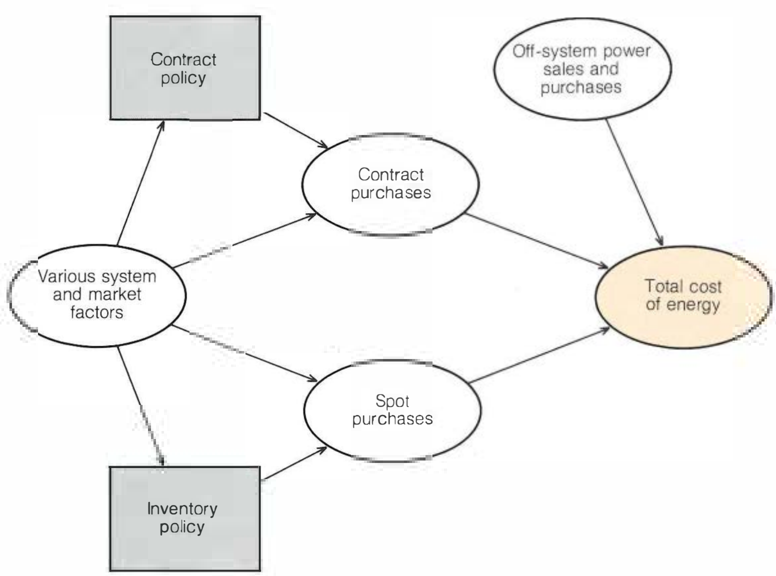


Figure 6 A simplified influence diagram, showing some of the factors that bear on the contract mix decision (spot market purchases versus contract purchases). The contract mix and inventory policies are controlled by the utility, whereas the other factors, such as the amount of coal burned and its price, are variable and unpredictable. The uncertain outcome is the total cost of energy to the consumer over time.

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

SMALL-HYDRO ACTIVITIES

Hydroelectric generation was introduced 100 years ago this year when a 12-kW plant with a 10-ft (3-m) head began operation in Appleton, Wisconsin. Following several decades of declining enthusiasm for small-hydro generation, this year's centennial, Fox Valley Festival of Lights, at Appleton marks what could be the start of a new era for small-hydro. In 1981, 1800 project permit applications were filed with the Federal Energy Regulatory Commission, up from only 12 in 1975. Utilities, local governments, and private developers have enthusiastically sought sites for development. However, high development costs suggest that only 20–25% of the 8700 MW of potential small-hydro capacity (1–15 MW) can be economically developed. Compounding this problem are the delays associated with interfacing this source of energy with the utility grid and with meeting regulatory and environmental requirements. Helping utilities and others to evaluate sites and reduce costs has become a major objective of the Energy Storage and Hydroelectric Generation Program.

In 1980 EPRI initiated an extensive review with utility industry representatives and others to identify the crucial hydro R&D issues and establish the priorities for EPRI efforts in hydroelectric R&D. An R&D workshop was held with utility, architect-engineer, government, consultant, and supplier representatives in June 1980 at Dillin, Colorado, to establish the critical issues. The results of this workshop were incorporated in a questionnaire that solicited an identification of the relative priorities for EPRI efforts to address the respective issues. EPRI analyzed the questionnaire responses (50 in all) from a cross section of the hydro community similar to that represented at the workshop. The responses indicated the highest priority R&D category was reducing small-hydro costs, followed by improving operation and maintenance and reducing forced outages in large hydro installations. Small-hydro's renewed popularity results from several factors: there are many potential sites; costs are attractive for third-party venture capitalists; opportunities exist for R&D; and incentives have been provided by various federal and state actions.

Based on the results of the workshop and questionnaire, EPRI has initiated small-hydro R&D efforts that emphasize the following.

▫ Site screening. EPRI supported the development of a manual, *Simplified Methodology for Economic Screening of Potential Low-Head, Small-Capacity Hydroelectric Sites* (EM-1679), which describes step-by-step procedures to estimate a site's power and energy output, evaluate the probable cost of developing a potential site, and perform preliminary economic design. Three seminar-workshops, centered on this manual, transferred to 200 participants the methods to identify and evaluate possible sites; analyze their potential; rank them in order of technical, economic, and institutional feasibility; and select those most attractive for continued investigation.

▫ Development experiences. DOE and EPRI are cooperating on documenting and transferring the actual experiences encountered during site development. DOE is funding 20 small-hydro demonstrations that represent a great diversity of ownership, site conditions, and geographic locations. These and other projects will be reviewed with emphasis on licensing and cost documentation. DOE and EPRI have issued an RFP for this work.

▫ Cost reduction. Capital cost may be significantly reduced by R&D aimed at modularizing and standardizing small-hydro plants, using submerged screen intakes with siphon penstocks constructed with low-cost material; standard prefabricated metal buildings for powerhouse superstructures with simple mass concrete foundations; standard industrial vertical pumps used as turbines (PATs); standard induction motors used as generators; and standardized auxiliaries, including electrical circuits, existing switchgear, sensors, and programmable controller.

Typical small-hydro plants will cost about \$2000/kW, although costs vary substantially from site to site (the standard deviation for the capital cost is around \$600/kW). The major cost items are the civil features (15–45%), turbine generator (18–39%), and indirects (30%). When standardized and prefabricated, the components described above should significantly lower site development costs. Similar approaches applied to minihydro (<1 MW) showed that development costs could be reduced by \$800–\$1000/kW.

An assessment of cost reduction potential for small-hydro sites was initiated earlier this year by Acres American, Inc. (RP1745-6). The objective of this project is to establish accurate costs of a standardized and pre-

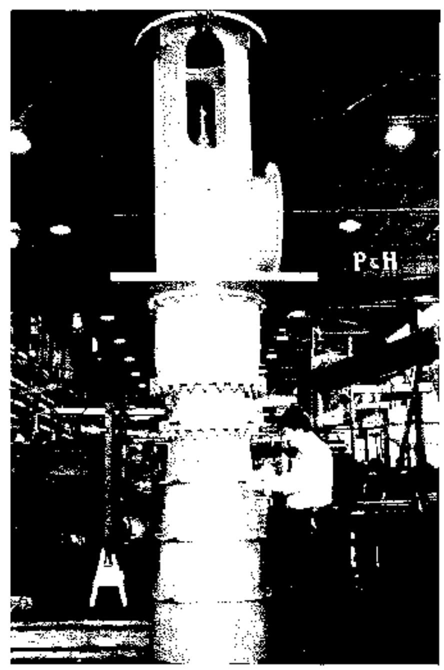


Figure 1 Ingersoll-Rand vertical pump tested as a turbine: 32-ft (10-m) head; 55 ft^3/s (1.56 m^3/s). The testing produced near-peak efficiencies, 85%, at heads from 30 to 60 ft (9–18 m). The test pump is a one-third-scale model of the largest pump that is currently part of the Ingersoll-Rand line; so the test results can be applied for flows up to 600 ft^3/s.

fabricated energy delivery system, consisting of the components described above, for two actual sites as example applications. Such a system could increase the number of feasible sites and help utilities expedite small-hydro development plans.

Pumps have been used in reverse as turbines since at least 1924, and more recently their performance has been tested under a DOE contract with Ingersoll-Rand Research, Inc. Many major pump manufacturers have also collected data on their own pumps' operation as turbines, and based on specific head and flow conditions, will recommend a specific pump for such a turbine application. PATs have significant advantages.

- They are less costly and less complicated than turbines.
- They are simpler to operate and maintain.
- PATs are not custom-made but have been designed and therefore are more quickly manufactured and delivered.
- They can be delivered prefabricated and ready for installation.
- The installation is simple, requiring only a mounting plate.
- The bearings require only water for lubrication, not a pressurized lubrication system.

PATs are also an economic choice at sites where pumped storage is planned. Figure 1 shows a typical pump that has been tested for turbine service.

At nonpower dams, penstock installation can be a large portion of the power development cost. A siphon penstock (Figure 2) can reduce that cost and maintain dam integrity. (At least three are currently operating in the world.) The principal limitation of the siphon penstock is that it can only raise water over the top of the dam to a height equal to the local barometric pressure (34 ft maximum). Siphon penstocks have three major advantages—they lower the cost of installation on sites at which the dam does not have acceptable penetrations; the dam integrity is not compromised; and they are accessible for examination.

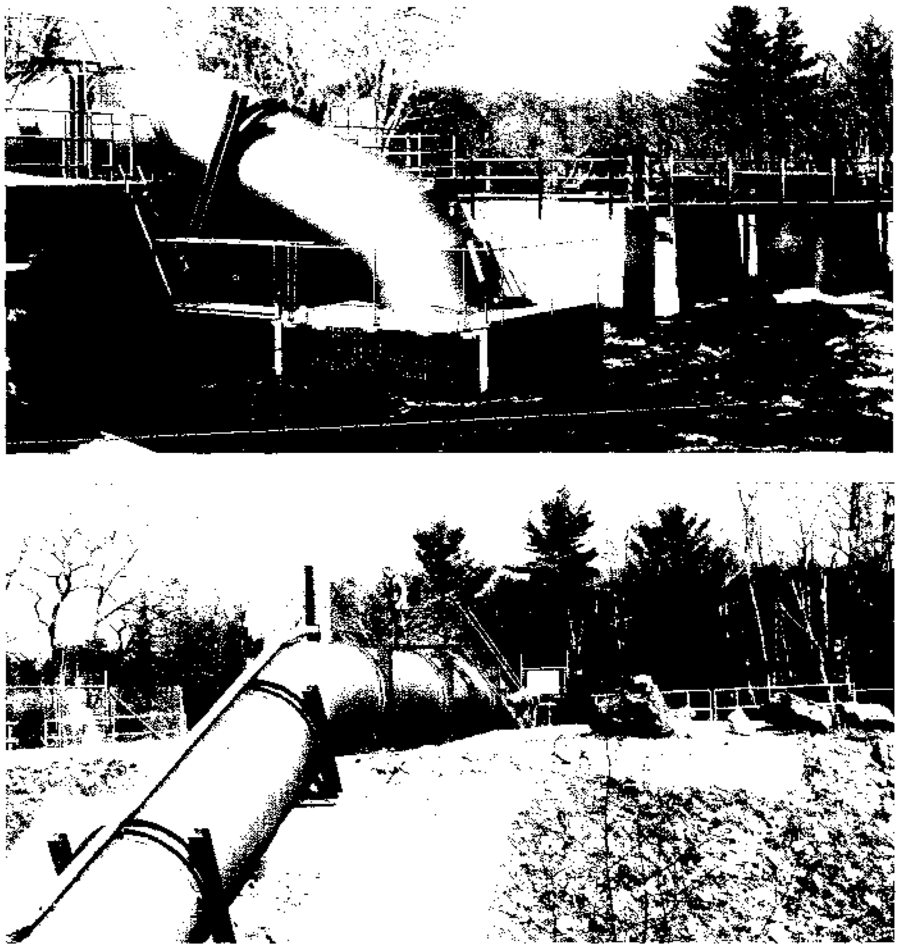
Conventional synchronous generators are large and expensive. Induction motors used as induction generators can be less expensive, and they have been successfully applied to hydro systems for at least 30 years. The size and cost of induction generators decrease as the operating speed increases, which can be accomplished by adding a speed increaser at the generator input side. One restriction is that the induction generator must be operated within a range above its synchronous speed but within limits set by its connection to the grid. However, the siphon vacuum control could possibly be used to regulate the flow and satisfy this requirement. Induction generators have two major advantages—they do not require a dc exciter, synchronizing, or complex regulating systems for voltage and speed; the higher-speed induction generators are smaller, less costly, more efficient, and have a better power factor.

Acres American will also study small-hydro sites that could incorporate these systems and will estimate equipment performance, reliability, operation, maintenance, and cost. Cost-risk and investment analysis for the system will be compared with that of conventional turbine generator equipment. The project will examine the feasibility of standardizing equipment for a wide range of head and flow at different small-hydro sites and propose standardized equipment and plant design, including automated control and auxiliary systems.

Two case studies will be evaluated for capital cost, cost uncertainty, performance, reliability, operation, and maintenance. In both studies the complete new system will be compared with conventional approaches. Performance will be based on site hydrology, head conditions, and equipment efficiencies. These studies will be used to determine relative total costs of the two concepts.

Acres American will develop an easy-to-use reference manual for equipment application and cost-effectiveness. The manual will include basic technical data, performance curves, and costs of all equipment

Figure 2 The Wasdell Falls siphon penstock system. This prefabricated hydroelectric power station incorporates a 6-ft (1.8-m) inner diameter siphon penstock operating with a net head of 12 ft (3.7 m). The siphon has a steel intake trash-rack screen (top) and is supported on the surface of the dam (bottom) as it proceeds to the powerhouse. Although the site is 93 mi (150 km) north of Toronto, icing problems have not been experienced.



investigated in this project. Proposed standardized designs for auxiliary systems, including automated control systems, will be presented, as well as simulation computer programs for both PAT and conventional turbine design curves. The document will also examine reliability and cost-risk effects on investment analysis. Acres American will prepare a development plan for a full-scale field test, including site selection, layout, equipment selection, cost, and program schedule.

The project is scheduled to conclude February 1983 and the final report will be published shortly thereafter. EPRI is considering a full-scale field test if economics of the standardized energy delivery system are sufficiently attractive. Utilities interested in cost-sharing and hosting this test should contact the project manager. *Project Manager: Charles Sullivan*

LOAD MANAGEMENT AND CONSERVATION

Systems Control, Inc., has developed a computer program that can simulate the effects of residential customer-side energy management strategies on utility system loads (RP1833-1). The program—LOADSIM—is an engineering model of the electric power demand patterns of various types of residences. It accepts demographic information, appliance saturation statistics, weather patterns, and building characteristics. It also predicts hourly load shapes in response to such load management strategies as air conditioning cycling and hot water heater control and such conservation measures as passive solar technology and weatherized homes. In addition to load shapes, the program predicts parameters, such as indoor humidity and temperature, that determine customer comfort level. To date, LOADSIM has been calibrated and tested by four utilities to verify its reliability and accuracy.

Energy management pilot programs

Since 1978 the number of utility-sponsored pilot programs for testing energy management strategies has approximately doubled every two years. These pilot programs are designed to estimate the effect of many new energy management strategies on utility systems. They are important tools in determining whether or not a particular load management or conservation strategy will produce the desired results. However, testing a large number of control strategies is impractical and requires a long time (two heating and/or cooling seasons for each strategy) to obtain reliable results. In addition, pilot programs measure effects only at the time the program is conducted, and they cannot take into account future changes in system conditions, such as changes in appliance stock, appliance efficiencies, or customer living patterns. Moreover, these programs can be very expensive, especially if a large number of data points are measured to provide confidence in the results. LOADSIM complements pilot programs and can help utilities develop needed information by addressing these problems. It can simulate a large number of energy management strategies and select a few preferred ones to be later confirmed by a pilot program. Also, it can predict the long-term effects of energy management programs, taking into account demographic changes, improvements in appliance stocks and efficiencies, and changes in housing construction standards.

LOADSIM program quality can be validated by field data collected by utilities in pilot energy management programs. This process consists of two tests: the first to verify that the program can correctly predict load-shape changes that result from energy management programs at the customer household level and the second to verify that it can predict diversified load-shape changes at the utility system level.

Host utilities

Early in program development it became apparent that to be of value to utilities, LOADSIM would have to be verified by field data. Consequently, utilities were asked to participate. The Detroit Edison Co. offered to provide its extensive in-house load research data collected through a system-wide water heater control program and a substation-level air conditioning cycling experiment.

The LOADSIM program test on the Detroit Edison system had four goals.

- To prove that LOADSIM could accept typical utility load research data
- To establish that it could be calibrated to yield sufficiently reliable load-shape predictions when checked against field data
- To confirm that its output could be integrated with utility system planning and corporate planning computer programs, which perform economic evaluation of energy management alternatives
- To ensure that LOADSIM would provide sufficient confidence for utility management to rely on its predictions as the basis for major corporate decisions on energy management programs

Detroit Edison used LOADSIM to evaluate its electric water heater load management control efforts, and each of the four goals was accomplished. The results have been a key input to Detroit Edison's plan to revamp its water heater control program.

To increase confidence in LOADSIM's applicability and usefulness, three additional host utilities were asked to participate in its evaluation. Pacific Gas and Electric Co. agreed to evaluate the model in simulating its air conditioning control strategies. Southern Company Services, Inc., and Gulf Power Co. offered to compare results of their smart thermostat pilot programs with the model's simulated results. United Power Association put forward its field data on heat storage experiments for evaluation. In addition, Detroit Edison continued testing LOADSIM against field data obtained from its air conditioning cycling experiments.

Analysis of each of these programs is ongoing, and valuable results, in terms of both LOADSIM application and the need for program refinements, are evolving. A more extensive user's guide has been requested because the program requires the user to have rather detailed knowledge of building and HVAC engineering. Utilities have also indicated that although the model provides accurate simulation of heat balance and appliance characteristics, it cannot adequately simulate a random user's living pattern. Moreover, comprehensive computer program documentation is necessary, including test runs to check that the program is functioning properly. Host utilities have indicated that LOADSIM's principal advantage is that it can be used as a planning tool for load management and conservation efforts. They also noted its usefulness in forecasting future changes in electricity demand and energy use as a result of conservation and load management policies.

In response to these suggestions, a comprehensive computer program documentation and a user's guide are now being developed. The program is being further refined with utility help, especially the subroutine dealing with aggregation of electricity demand from the household level to the system level. Both tasks are expected to be completed shortly.

A workshop to present the model and to share host utility experiences will be scheduled later this year. The program is expected to have sufficiently matured for direct transfer to utilities. EPRI will continue to support upgrading the program and, if there is sufficient interest, will help initiate an industry-supported users group. *Project Manager: Timothy Yau*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

SEQUOYAH PLANT AVAILABILITY ANALYSIS

The recent emphasis on nuclear plant probabilistic risk assessment has resulted in expanded activities in system analysis. EPRI and the Tennessee Valley Authority are cosponsoring a project (RP1842) to develop and demonstrate a state-of-the-art probabilistic system analysis technique to serve as an alternative to the WASH-1400 technique. In this project the GO methodology is being used to characterize plant availability and reactor safety for TVA's Sequoyah nuclear plant. This report describes the GO methodology and its application to a full-scale availability assessment of the Sequoyah plant.

The GO methodology was adapted from the defense industry and has been further refined to incorporate some power plant modeling requirements. The methodology, in contrast to fault/event tree analysis, is a success-oriented system analysis technique and employs inductive logic to model system performance (NP-765, -766, and -767).

A GO model, which is composed of a set of GO symbols, represents the engineering function of a component, subsystem, or system. It can be constructed directly from engineering drawings by replacing engineering elements, such as valves and switches, with the equivalent GO symbols. (There are 17 types of GO symbols.) These GO symbols are then linked together according to engineering system performance definitions to form the GO model. The GO computer code uses the model to determine all possible system response modes, both successes and failures, and to quantify system performance.

The methodology has the ability to evaluate system reliability and availability, identify system fault sequences, construct statistical inferences from the results, and rank the importance of a system's constituent elements to its performance. Certain unique features of the GO methodology are useful in modeling complex system performance.

- Modeling system interaction effects. A GO system model contains the engineering relationships of the components and subsystems of that system. Interactions between these constituents and between systems are part of GO model output.

- Modeling engineering common cause and common mode effects. Engineering common causes and modes are introduced because of the sharing of system boundary conditions. Certain systems—for instance, station electric power systems, control and service air systems, and various cooling-water systems—define the boundaries of all other systems in a nuclear plant. The GO model can integrate these common systems into a total plant model and can analyze the effects of this commonality on plant performance.

- Modeling of the man-machine interface and external events. Special dummy GO symbols can be introduced into the GO model to represent extraneous events, such as human maintenance errors, manufacturer design errors, and location-dependent failures (e.g., fire or flood).

The GO modeling technique has been used in many different applications, such as analyses of fossil fuel plants and geothermal plants. It appears to be more cost-effective and easier to communicate than other probabilistic system analysis techniques.

In the full-scale GO availability analysis of the Sequoyah plant, some 65 power-production-related systems are being modeled to predict plant availability at 100% rated power operation. These systems are classified into three general categories: main process systems (e.g., main feedwater, reactor coolant, reactor control, neutron monitor); plant support systems (e.g., communication, lighting, primary water makeup, lube oil); and plant auxiliary support systems (e.g., ac/dc power, control and service air, essential raw cooling water, component cooling water). The systems are modeled at various levels of detail to determine all possible success and failure modes of plant operation.

The preliminary Sequoyah GO availability model, which consists of approximately 9000 GO symbols, has been exercised by the GO computer code to quantify plant availability, to identify critical plant design features and potential weaknesses, and to rank the importance of various systems to plant availability. The preliminary analysis shows the overall plant availability at 100% rated power to be approximately 0.5. This value should not be taken literally, however, because the GO model is not yet fully developed and because the data base used in the evaluation is generic, not plant-specific for Sequoyah.

Qualitatively, the preliminary results indicate a lack of balanced system design. The unavailabilities of various systems differ by several orders of magnitude. For example, the main feedwater system has an unavailability of 0.2 and the electric power systems have unavailabilities of less than 0.001. The application of cost-benefit techniques to improve the balance of system design may be worthwhile from an economic standpoint.

The Sequoyah nuclear plant probabilistic study has demonstrated that the GO methodology can be effectively applied to plant availability analysis. Several preliminary quantitative results have indicated that nuclear power plant availability may be enhanced by improving some of the non-safety-related power production systems. The full-scale GO analysis of the Sequoyah plant is continuing; final results are expected to be available at the end of the year. *Project Manager: Boyer B. Chu*

SPEAR FUEL PERFORMANCE CODE

Zircaloy-clad LWR fuel rods have seen service for 25 years, having been introduced at the Shippingport reactor in 1957. Following a rash of problems in early commercial power reactors, successive refinements have led to

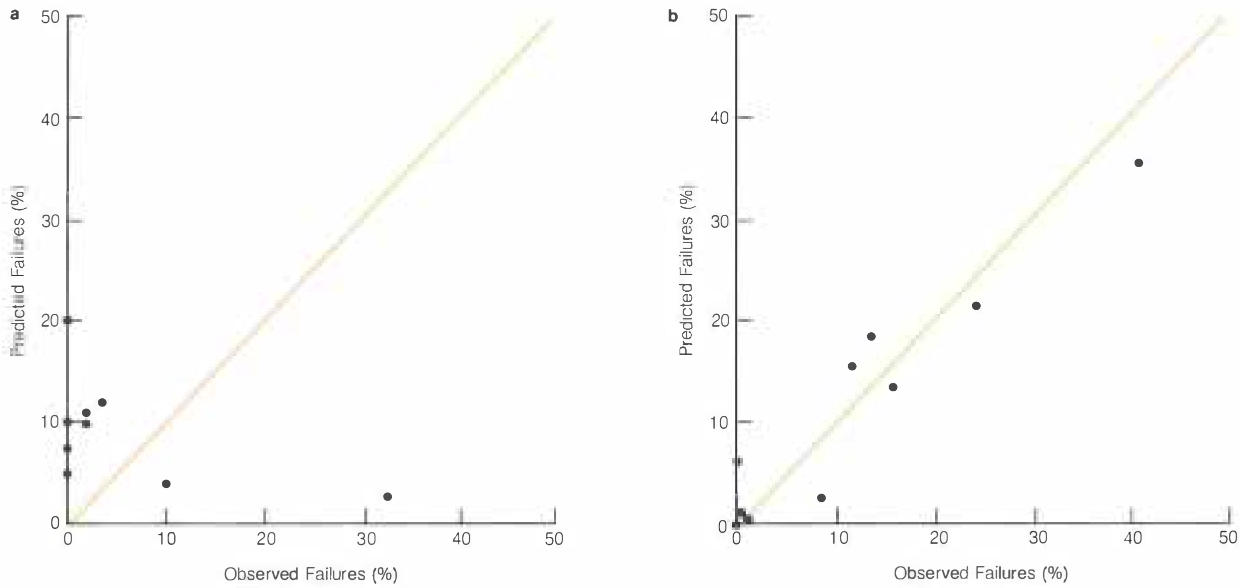


Figure 1 Predicted versus observed fuel failures (failed assemblies as a percentage of total assemblies) for **(a)** the FCODE mechanistic model and **(b)** the SPEAR hybrid system. Each data point represents 212 assemblies. SPEAR's superior prediction capability results from the linking of FCODE to a statistical model.

a generally satisfactory level of performance by this key reactor component. Nevertheless, the fuel rod remains a complex device whose design life is spent in a harsh chemical, mechanical, and radiation environment. Financial incentives for higher burnups, load-following operation, and the alleviation of power-maneuvering restrictions continue to draw utilities toward operating regimes in which they have limited experience. These incentives have provided the impetus for a national fuel research program, in which EPRI is participating. An important part of EPRI's effort is the development of the SPEAR code for predicting fuel performance.

In connection with the national fuel research effort, irradiation results from DOE and EPRI programs in more than 26 power and test reactors around the world are input to the computerized National Fuel Performance Data Base. Much of the experience gained in this research has been incorporated into EPRI's SPEAR fuel performance code system. By making inexpensive SPEAR computer simulation runs, utilities can take advantage of this experience before risking financial and hardware resources on a new design or a different operating regime. A new version of SPEAR, designated the BETA version, has recently been released through the Electric Power Software Center.

SPEAR is an example of what systems analysts term a hybrid predictive system because it contains both mechanistic (first principles) models and statistical (empirical) models. The models are interlinked in such a way that predictions produced by the complete SPEAR system are superior to the combined predictions of its mechanistic and statistical parts.

SPEAR's central mechanistic model is called FCODE. In the recently released version of SPEAR, FCODE has been improved by extending its submodels to cover phenomena up to a fuel centerline temperature of 2000°C. (The previous limit had been 1400°C.) Thus the model now covers the range of normal power reactor fuel operating temperatures.

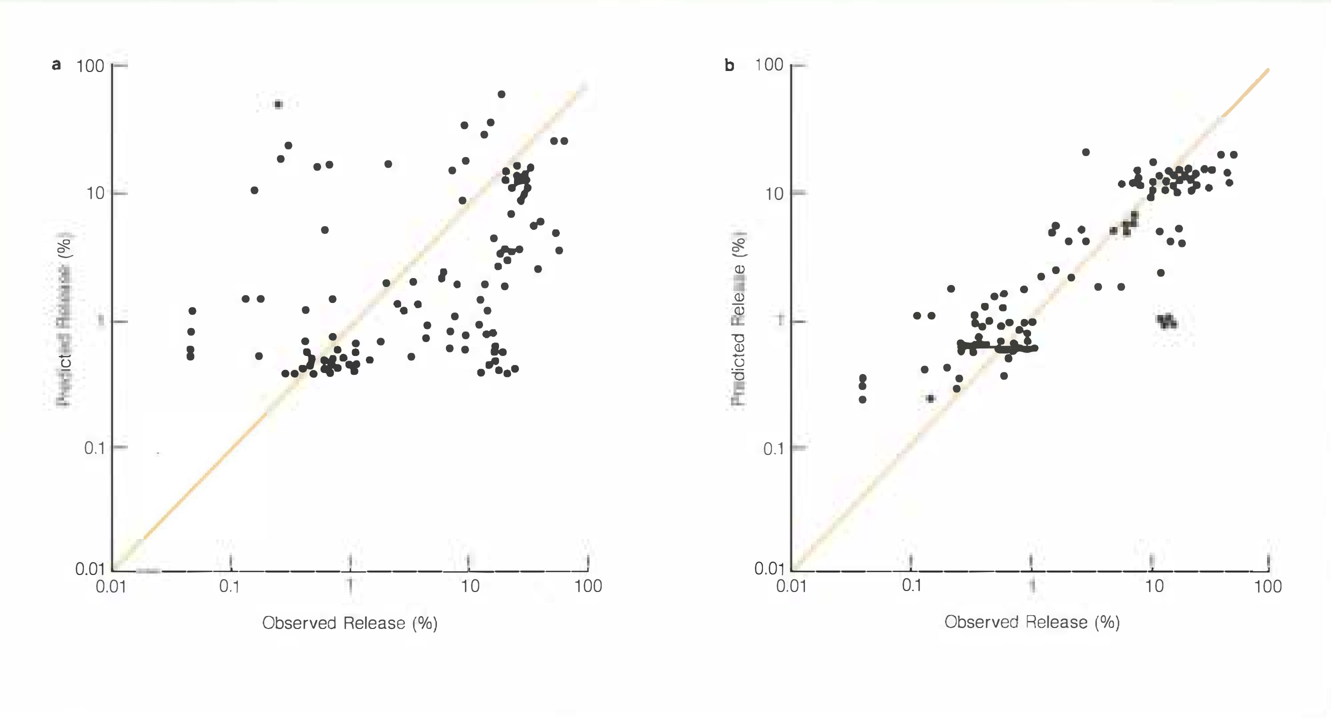
FCODE can be used by itself for such tasks as fuel temperature and cladding creep strain analysis. A study for EPRI by Science Applications, Inc., has concluded that FCODE exhibits errors in centerline temperatures of about 200°C—a magnitude of error that is expected in codes of this type and that is tolerable in most applications.

For more difficult predictive challenges than fuel temperatures, SPEAR's hybrid capabilities can be beneficially exploited. To estimate whether a given fuel assembly will fail in service (i.e., will be found, on radiochemical sipping, to leak fission products), the user first simulates assembly operation with the mechanistic FCODE module.

FCODE's failure predictions are of little direct value to the user because they exhibit highly random scatter when compared with actual failure observations (Figure 1a). This randomness results from evident deficiencies in the model's treatment of the failure phenomena. It has been found, however, that the file of FCODE output data does contain predictive information about the failure status—for example, the amount of hot working to which the Zircaloy cladding is subjected during reactor power cycling and the amount of fission gas released during an upward power ramp. This file can be passed through SPEAR's statistical module, PATMAT, which combs it for such information. The hybrid FCODE–PATMAT model has been demonstrated to be a good failure predictor. As shown in Figure 1b, its predictions about percentages of assemblies that will fail are close to the observed percentages.

A similar situation results when the SPEAR system is used to predict fission gas release from UO_2 pellets during operation. Used

Figure 2 Predicted versus observed fission gas release (amount of gas released as a percentage of gas produced) for **(a)** FCODE and **(b)** SPEAR. Again SPEAR shows superior prediction capability.



alone, the FCODE module produces predictions that show a high degree of random scatter when compared with observations of fission gas release (Figure 2a). When combed by the statistical module PATMATF, however, FCODE's output data file yields substantial information about fission gas release in fuel rods. Among the features of the file that have predictive value are (1) the cumulative axial shift of the peak burnup position on the rod, and (2) the maximum lifetime value of the quotient of linear heat generation rate and fission gas release per unit area of cladding. Predictions by the hybrid FCODE–PATMATF system, as compared with observations, exhibit much less scatter than the FCODE predictions (Figure 2b).

The analyses performed in preparing the statistical models PATMAT and PATMATF have yielded some new insights into the phenomena associated with cladding failure and fission gas release. For example, the results suggest that a certain level of lifetime cumulative plastic strain (along with other conditions, such as adverse internal rod chemistry) is necessary for the initiation of cladding failure. Earlier theories had suggested only that a certain level of peak lifetime stress (plus adverse internal rod chemistry) was necessary.

Another interesting finding was that fission gas release is affected to a significant degree by details of the power-time history (e.g., ramp rates) experienced by a fuel rod. Earlier models have assumed fission gas release to be determined by a fuel rod's temperature-time history and to be unaffected by the power-time history.

SPEAR is being installed in the BWR version of the power shape monitoring system (PSMS), where it will provide utilities with an on-line capability for fuel reliability monitoring and prediction. In a recent on-line test simulating conditions during cycle 8 at the Oyster Creek reactor, PSMS predicted that one to three failed bundles would be found among the 484 bundles analyzed. The number of failed bundles actually found by sipping was two. In another study, Systems Control, Inc., will look at fuel reliability as a problem of control and will examine how SPEAR–PSMS might be used to achieve reliability in a more cost-effective manner.

A version of PSMS that includes SPEAR is scheduled for release by the Electric Power Software Center in August 1982. *Project Manager: S. T. Oldberg*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1196-2	Rotary Separator–Turbine Field Test at Milford, Utah	6 months	125.0	Utah Power & Light Co. *E. Hughes*
RP1654-14	Gasification–Combined-Cycle Demonstration Plant, Operations Test Planning Support	2 years	30.0	Philadelphia Electric Co. *J. McDaniel*
RP2101-1	Gas Turbine Control System Reliability Analysis and Verification	26 months	1281.8	General Electric Co. *A. Dolbec*
RP2147-4	Influence of Hydrogen Bonding on Liquefaction	18 months	135.0	Rockwell International *L. Atherton*
RP2147-5	Reaction Mechanisms in Coal Liquefaction	6 months	38.0	SRI International *L. Atherton*
Coal Combustion Systems				
RP1266-29	Study to Optimize the Combustion Efficiency of an Oil-Fired Multiple-Burner Utility Boiler	8 months	32.0	Babcock & Wilcox Co. *J. Dimmer*
RP1400-11	Coal Cleaning Test Facility, Development of Test Plans	4 months	221.0	Science Applications, Inc. *F. Karlson*
RP1867 5	10-MW High-Sulfur Coal Fabric Filter Pilot Plant, Operation and Maintenance	27 months	525.7	Southern Company Services, Inc. *W. Piulle*
RP1872-3	Site Verification of Scrubber Component Failure Data Sheets and Model Development	1 year	93.7	Bechtel Group, Inc. *T. Morasky*
RP1891-02	CEGB Experience in Slagging and Fouling of Pulverized-Coal Utility Boilers	5 months	38.1	Central Electricity Generating Board *J. Dimmer*
RP1961-3	Continuous Emission Monitor: Development and Evaluation, Phase I	25 months	299.0	Kilkelly Environmental Associates, Inc. *C. Dene*
RP2214-1	Assessment and Evaluation of Cooling-Water Intake Systems	2 years	297.5	Tetra Tech, Inc. *J. Bartz*
Electrical Systems				
RP1095-15	Galloping Control by Detuning	34 months	48.7	Aluminum Co. of America *P. Landers*
RP1352-3	Cost-Effectiveness Evaluation of Environmental Loading Requirements for Probability-Based Design	11 months	46.6	Stanford University *P. Landers*
RP1605-1	Development of Helical Foundation	19 months	177.4	Kinnan & Associates *P. Landers*
RP1712-3	Power System Security Analysis and Demonstration Work Plan	3 months	37.7	ESCA Corp. *C. Frank*
RP7801-37	Waltz Mill ±600-kV DC Cable Installation, Phase III—Task Agreement	9 months	405.6	Westinghouse Electric Corp. *J. Shimshock*
Energy Analysis and Environment				
RP1050-6	Seminar: Cogeneration	6 months	62.5	Synergic Resources Corp. *L. Williams*
RP1431-2	Intermediate-Term Coal Supply Constraints—Coal Price Sensitivity	3 months	100.0	ICF Incorporated *J. Platt*
RP1630-26	Field Studies in Conjunction with the U.S. EPA June 1982 Dry Deposition Intercomparison Study	10 months	46.9	Battelle, Pacific Northwest Laboratories *R. Patterson*
RP1743-4	Analysis of Water Resources Research	8 months	32.7	KVB, Inc. *R. Brocksen*
RP1987-2	Decision Framework for New Technologies, Considering Size and Location	10 months	163.0	Systems Control, Inc. *S. Mukherjee*
RP2040-2	Electric Fields Decision Framework	3 months	29.2	Decision Focus, Inc. *L. Rubin*
RP2046-2	Framework for the Complementary Use of Mathematical Models and Microcosm Experiments	8 months	50.9	Tetra Tech, Inc. *R. Kawaratani*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Energy Management and Utilization				
RP1136-16	Electric Vehicle Conference	6 months	30.0	Electric Vehicle Council *J. Mader*
RP1276-12	Electric Power for Industrial Parks, Preliminary Study	5 months	21.4	Energy Conversion Associates *D. Hu*
RP1745-2	Pump Turbine Model-Prototype Correlation Survey	13 months	96.9	Southern Company Services, Inc. *C. Sullivan*
RP1791-10	Compressed-Air Energy Storage, Technology Transfer Analysis	20 months	175.0	Reynolds, Smith & Hills, Inc. *R. Schainker*
RP1832-3	Economic Feasibility of Energy Storage for Small Utilities	15 months	143.8	Burns & McDonnell Engineering Co. *T. Yau*
RP2033-6	Hydronic Heat Pumps	1 year	184.4	Battelle, Columbus Laboratories *J. Calm*
RP2034-2	R&D Needs in Management of Lighting Energy	7 months	25.0	Pacific Gas and Electric Co. *A. Lannus*
Nuclear Power				
RP347-2	Development of a New Physically Based Correlation for LWR Cooling-Pump Performance Under Two-Phase Conditions	13 months	98.6	Tetra Tech, Inc. *J. Kim*
RP495-2	Two-Fluid Modeling of Flow Instability in BWRs and Steam Generators	22 months	81.1	Arizona State University *S. Kalra*
RP959-3	Assessment of Rewetting and Boiloff Data and Models for LWR Applications	18 months	131.2	University of California at Berkeley *B. Sun*
RP1557-7	Radwaste Dose Rate to Curie Conversions	9 months	58.9	NWT Corp. *M. Naughton*
RP1557-8	Vitrification of Low-Level Radioactive Wastes	9 months	45.0	Battelle, Pacific Northwest Laboratories *M. Naughton*
RP1637-3	Seminar: Human Factors Design Guidelines for Nuclear Power Plants	4 months	29.2	Essex Corp. *H. Parris*
RP1842-4	Sequoyah Nuclear Power Plant Availability and Risk Assessment	3 months	316.9	Pickard, Lowe and Garrick, Inc. *B. Chu*
RP1842-5	Development of Modularized Generic GO Reliability/Availability Safety System Models	5 months	52.8	Energy Incorporated *B. Chu*
RP1845-6	ATHOS Analysis of GEST–GEN Steam Generator	6 months	33.9	CHAM of North America, Inc. *G. Srikantiah*
RP1845-7	RETRAN Analysis of Steam Generator Tests	7 months	50.9	Energy Incorporated *L. Agee*
RP1930-2	BWR Hydrogen Addition—In Situ CERT Testing and Equipment Evaluation	9 months	199.4	Commonwealth Research Corp. *M. Fox*
RP2007-1	Advanced Overpressure Protection for PWR Plants	13 months	207.0	Westinghouse Electric Corp. *B. Brooks*
RP2009-4	Guidelines for Internal Plant Communications	11 months	90.3	General Physics Corp. *J. O'Brien*
RP2012-3	Characterization of TMI-2 Coolant System Contamination	5 months	134.2	Science Applications, Inc. *K. Winkleblack*
RP2061-4	SPEAR Code Development, Maintenance, and Support	4 months	31.1	Entropy Limited *T. Oldberg*
RP2061-5	Analyze SPEAR–ECODE–BETA	5 months	28.6	Battelle, Pacific Northwest Laboratories *T. Oldberg*
RP2061-7	Fuel Failure Control in the BWR	3 months	50.6	Systems Control, Inc. *T. Oldberg*
RP2117-1	Removal of Radionuclides by Water Pools Under Severe Accident Conditions	27 months	930.5	Battelle, Columbus Laboratories *R. Oehlberg*
RP2164-2	Radiographic Inspection for TMI-2 Debris Location	8 months	74.0	Schonberg Radiation, Inc. *M. Lapides*
RP2166-1	Development and Test of a Preventive Maintenance Model	18 months	309.0	Pickard, Lowe and Garrick, Inc. *H. Parris*
RP2171-2	Quality Assurance Approach for LWR Probabilistic Risk Assessment	8 months	74.9	Energy Incorporated *D. Worledge*
RP2172-2	Concrete Containment: Structural Element Tests	10 months	232.0	Construction Technology Laboratories *G. Sliter*
RP2179-1	Hold-Down Bolt Inspection by Acoustic Resonance; A Proof-of-Principle Test	5 months	30.2	Sigma Research, Inc. *S. Liu*
RP2181-1	Improved Stress Corrosion Resistance of High-Strength, Age-Hardenable Ni-Cr-Fe Alloys (Phase II)	2 years	329.6	Babcock & Wilcox Co. *A. McIlree*
RP2184-1	Development of a Colorgraphic Display System Guide	1 year	120.0	Oak Ridge National Laboratory *J. O'Brien*
RP2230-1	Feedwater Heater R&D Planning Study	5 months	28.0	Mollerus Engineering *N. Hirota*

New Technical Reports

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

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

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others in the United States, Mexico, and Canada pay the listed price. Research Reports Center will send a catalog and complete price list (including foreign prices) on request.

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

ADVANCED POWER SYSTEMS

300-Btu Gas Combustor Development Program: Phase 2

AP-2221 Final Report (RP985-3); $16.50

This report presents the Phase 2 results of an effort to develop and test a gas turbine combustor capable of meeting EPA NO_x requirements when operated on medium-heating-value coal-derived gas without the use of water injection. Two lean-premix combustor designs were evaluated in Phase 2; the objectives were to improve the ease of fabrication and to extend the operating range of the Phase 1 designs. The contractors are United Technologies Corp. and Pratt & Whitney. *EPRI Project Manager: L. C. Angello*

Transient Phenomena in Coal-Fired MHD Generators: Electrical Effects of Slag in a Diffuse-Mode Generator

AP-2290 Final Report (RP468-3); $16.50

This report describes an analytic and experimental investigation of the effects of coal slag on magnetohydrodynamic (MHD) channel current and voltage distributions among electrodes. A numerical code is described that solves the governing electrical equations and the slag energy and thickness equations for a two-dimensional, periodic-electrode-pair slagging MHD generator. The analytic and experimental results are compared. The contractor is Stanford University. *EPRI Project Managers: A. C. Dolbec and Andrew Lowenstein*

Workshop on Evaluation of Engineering Opportunities in Inertial Confinement Fusion

AP-2317 Proceedings (RP1971-1); $10.50

This report documents an EPRI workshop held in November 1981 in New Orleans to evaluate engineering opportunities in inertial confinement fusion (ICF) in existing and planned facilities. The workshop brought together the ICF community and the experimental facilities community to define and rank experiments important to the engineering development of ICF. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: K. W. Billman*

High-Reliability Gas Turbine Combined-Cycle Development Program: Phase 2

AP-2321 Final Report (RP1187-2); Vol. 1, $28.50; Vol. 2, $36.00

This report documents work performed under Phase 2, the preliminary design phase, of a program to develop a gas turbine design with sufficient reliability to be considered for baseload service in a combined-cycle plant. Volume 1 describes a new centerline combustion turbine engine design and a combined-cycle plant component design. It also presents the results of a reliability, availability, and maintainability analysis and a cost-of-electricity analysis. Volume 2 presents a glossary and nine supporting topical reports. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: P. S. Zygielbaum*

Effect of Liquefaction Processing Conditions on Combustion Characteristics of SRC

AP-2328 Interim Report (RP1412-9); $16.50

Solvent-refined coal (SRC) solids produced by three liquefaction process variations (involving pressure filtration de-ashing, antisolvent de-ashing, and critical solvent de-ashing) were fired under laboratory and pilot plant combustion conditions to study their combustion characteristics. The extent of carbon burnout of the SRC fuels under simulated utility boiler conditions was assessed, as well as fuel preparation techniques required to minimize NO_x emissions while maintaining high combustion efficiency. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: W. C. Rovesti*

Plastic and Coking Behavior of Coals at Elevated Pressure

AP-2337 Final Report (RP1654-1); $10.50

A newly developed high-pressure microdilatometer was used to study the thermoplastic behavior of selected caking coals at high pressure. First, tests were conducted to demonstrate the device's performance over a range of gas pressures, heating rates, and coal particle sizes and to determine standard conditions for further testing. Then experiments were run with three coals over an elevated pressure range. The effect of mineral inclusions was also investigated. The contractor is Pennsylvania State University. *EPRI Project Manager: John McDaniel*

Survey of Electric Utility Gas- and Oil-Fired Boiler Population

AP-2342 Interim Report (RP1412-5); $15.00

This survey identified the size and location of the utility market for synthetic boiler fuel, as well as the characteristics of combustion equipment having the potential for deployment of these fuels. According to the survey, the dependence of utilities on natural gas and fuel oil is expected to continue for a number of years. The contractor is KVB, Inc. *EPRI Project Manager: W. C. Rovesti*

Evaluation of Materials for Use in Letdown Valves in Coal Liquefaction Systems

AP-2356 Final Report (RP779-17); $9.00

This report describes jet impingement–type tests conducted to evaluate the wear characteristics of letdown valve trim component materials. Nine advanced ceramic materials were assessed. Results of laboratory wear evaluations and service trials of letdown valves are presented. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: John Stringer*

Proceedings of the First Annual EPRI Contractors' Conference on Coal Gasification

AP-2394 Proceedings (WS81-199); $30.00

This report contains the technical papers presented at the first annual EPRI contractors' conference on coal gasification, which was held in October 1981 in Palo Alto, California. The conference sessions addressed pilot plant studies, commercialization prospects, process dynamics and control studies, and bench-scale studies. *EPRI Project Manager: G. H. Quentin*

Conceptual High-Performance, High-Specific-Output Silicon Photovoltaic Systems

AP-2408 Final Report (RP1348-3); $9.00

This report reviews development efforts and the current status of high-performance, high-specific-output silicon photovoltaic (PV) solar systems. Three system concepts are covered: (1) high-intensity irradiance from individual concentrators directly onto individual PV cells, (2) the redirection of sunlight by a large dish concentrator into a cavity receiver lined with cells, and (3) the redirection of sunlight by a large dish concentrator into a thermophotovoltaic receiver. Key issues, technical risk, and estimated performance are discussed for each system. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Manager: R. W. Taylor*

COAL COMBUSTION SYSTEMS

Coal-Oil Mixture as a Utility Boiler Fuel

CS-2309 Final Report, Vol. 1 (RP1455-2); $18.00

This report provides guidelines to the electric utility industry for the evaluation of coal-oil mixtures (COMs) as a replacement fuel in boilers designed to fire oil. The technical and economic information presented is based on an analysis of four existing oil-fired boilers that represent COM conversion candidates. This volume covers a COM firing performance analysis, boiler and plant modifications required for COM conversion, a detailed conversion cost and economic analysis for the four study boilers, and a generalized cost estimation methodology for COM conversion application. The contractor is Atlantic Richfield Co. *EPRI Project Manager: R. K. Manfred*

Cycling of High-Pressure Steam Power-Generating Units With Drum Boilers
CS-2340 Final Report (RP1034-1); $19.50

Cycling tests were conducted on a 500-MW high-pressure power-generating unit with a drum-type boiler, and an analytic model of transient boiler operation was developed. Cycling problems and methods to reduce them are summarized, and a suggested procedure for optimizing cycling operation of the test unit is presented. The contractors are the Tennessee Valley Authority; Combustion Engineering, Inc.; and Mechanical Technology, Inc. *EPRI Project Manager: J. P. Dimmer*

Dowa Process Demonstration
CS-2359 Final Report (RP1033-2); $25.50

A prototype-scale (10-MW) Dowa flue gas desulfurization system was evaluated at the EPA test facility at the Tennessee Valley Authority's coal-fired Shawnee steam plant. The Dowa process is an aluminum-based dual-alkali process that uses limestone and forced oxidation and produces a gypsum by-product. This demonstration examined the process's feasibility and SO_2 removal efficiency, as well as critical design parameters for a full-scale application. The contractors are TVA and UOP, Inc. *EPRI Project Manager: C. E. Dene*

Plant Monroe Sulfur Meter Evaluation
CS-2365 Final Report (RP1030-17); $16.50

The performance of an apparatus for the continuous measurement of the sulfur content of power plant feed coal was evaluated at a 3000-MW station. The device, called a sulfur meter, nondestructively examines a sidestream of coal by using prompt neutron activation analysis. Sulfur meter measurements were compared with those obtained by traditional ASTM chemical techniques; agreement was satisfactory. The contractor is Bechtel Group, Inc. *EPRI Project Manager: O. J. Tassicker*

Acoustic Emission Monitoring of Steam Turbines
CS-2367 Final Report (RP1266-14); $12.00

This report describes work to develop a method for the on-line detection of crack growth in steam turbine rotors based on acoustic emission (AE) monitoring. It outlines a systematic study to evaluate the potential for the detection and correct identification of crack growth AE signals during various turbine operating conditions. Preliminary turbine testing, monitoring equipment selection, rotor material laboratory testing, on-line source location and characterization, and stress analysis are described. The contractor is Rockwell International Corp. *EPRI Project Manager: A. F. Armor*

Feasibility of a 100-MW Wellman-Lord/Resox FGD Demonstration Plant
CS-2405 Final Report (RP1258-2); $15.00

This study determined the feasibility of demonstrating a Wellman-Lord/Resox regenerable flue gas desulfurization system at the 100-MW size. Using the Arthur Kill station of Consolidated Edison Co. of New York, Inc., as a potential site, the study covered site evaluation, preliminary design, capital cost estimating, and scheduling. The contractor is Stearns-Roger Engineering Corp. *EPRI Project Manager: Dorothy Stewart*

ELECTRICAL SYSTEMS

Phase 2: Frequency Domain Analysis of Low-Frequency Oscillations in Large Electric Power Systems
EL-2348 Final Report (RP744-1); 5 vols. (priced per vol.)

This report describes the development of a full-scale production program for the study of oscillations in large power systems. Volume 1 presents the basic concepts, mathematical models, and computing methods of the program, called AESOPS. Volume 2 covers data preparation instructions and program reference materials; Volume 3, studies of a large-scale system with 133 synchronous machines and two dc lines; Volume 4, three reports on linear system models; and Volume 5, studies of a 296-generator system. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. W. Lamont*

Array and Parallel Processors in On-Line Computations
EL-2363 Final Report (RP1355-2); $10.50

This report classifies parallel processors and discusses previous EPRI-sponsored work indicating that the array processor holds special promise for use in power system simulation problems. A complete ac power flow code was developed for an array processor and its host computer. Using this optimized code, the processor was able to solve the IEEE standard 118-bus power flow in less than 2.5 ms. On the basis of this work, an array processor can reasonably be expected to solve a 1000-bus flow in less than 0.5 second. The contractor is Cornell University. *EPRI Project Manager: J. V. Mitsche*

Phototransistor Switch for Breaker Applications
EL-2395 Final Report (RP1511-1); $12.00

An effort to develop a high-power light-driven transistor was undertaken with a view toward installing it in parallel with a mechanical circuit breaker to relieve stresses inherent in opening mechanical breakers under high-power fault conditions. This report describes the development of a process suitable for fabricating high-voltage transistors and presents the results of experiments on prototype devices. The contractor is General Electric Co. *EPRI Project Manager: Gilbert Addis*

Detection of High-Impedance Faults
EL-2413 Final Report (RP1285-1); $15.00

This report describes a statistical algorithm for detecting high-impedance faults that is based on changes in sequence current unbalance. Staged fault tests were combined with measurements of unfaulted system operations to evaluate the algorithm. The contractor is Power Technologies, Inc. *EPRI Project Manager: H. J. Songster*

HVDC Transmission Line Research
EL-2419 Interim Report (RP1282-2); $21.00

This report presents the results of work on the corona- and insulation-related performance of HVDC transmission lines. Tests of two different conductor geometries on a bipolar test line were conducted to evaluate audible noise, radio interference, corona loss, electric field, and ion performance. In the area of insulation, research focused on parameters that influence the flashover strength of contaminated insulators and of air gaps. The contractor is General Electric Co. *EPRI Project Manager: J. H. Dunlap*

Transmission Line Reference Book, 345 kV and Above: Second Edition
EL-2500 (RP68); $55.00

This book is intended to serve as a source of technology and data for the electrical design of EHV and UHV transmission lines up to 1500 kV. Much of the information was developed at Project UHV over the past 20 years. Four major design areas are treated: insulation, corona performance, electric and magnetic fields, and circuit performance (including conductor characteristics). In each area, a common set of base case circuit designs is analyzed to highlight items affecting design. The contractor is General Electric Co. *EPRI Program Manager: Richard Kennon*

ENERGY ANALYSIS AND ENVIRONMENT

Residential Demand for Energy
EA-1572 Final Report, Vol. 1 (RP1098); $16.50

This research describes, updates, and improves the residential demand models developed in RP431 that are currently used in EPRI's Demand 80/81 Model. Aggregate econometric models of residential demand for electricity, natural gas, and fuel oil were estimated by using time series data by state. Technical problems caused by declining-block pricing of electricity and natural gas were accounted for. The contractor is Data Resources, Inc. *EPRI Project Manager: S. D. Braithwait*

Integrated Forecasting Model Synthetic Fuels Study
EA-2358 Final Report (RP1108-1-4); Vol. 1, $15.00; Vol. 2, $21.00

The Integrated Forecasting Model (IFM) was used to assess the future of the U.S. synthetic fuels industry, with particular emphasis on the consequences for the electric utility industry. Volume 1 presents an overview of the model, the study, and the findings. Volume 2 describes the nature of the IFM, including its basic conversion process, depletable resource process, and network structure. The input data are also detailed. The contractor is Decision Focus, Inc. *EPRI Project Manager: L. J. Rubin*

Feasibility of Liming as a Technique to Mitigate Surface Water Acidification
EA-2362 Interim Report (RP1109-14); $12.00

This report presents a feasibility study of the use of liming to mitigate surface water acidification. The study addressed the application of calcium-based alkaline materials to lakes and waterways. Experimental and operational liming programs and techniques are discussed. Also covered are types and combinations of alkaline materials; input location; delivery modes; costs; and assessments of potential chemical, physical, and biological changes resulting from lime application. The contractor is General Research Corp. *EPRI Project Managers: R. W. Brocksen and R. K. Kawaratani*

Evaluation of Terrestrial Microcosms for Assessing Ecological Effects of Utility Wastes

EA-2364 Interim Report (RP1224-5); $16.50

This report presents the results of the first two years of a research effort to develop and evaluate a microcosm methodology for determining the effects of fly ash deposition on agricultural ecosystems. The three major parameters studied were crop yield (productivity), nutrient stripping (loss in soil water), and trace element fate (uptake in plant tissues). Microcosm results on net primary productivity and the uptake of 16 potentially toxic trace elements are compared with results from field plots. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: R. W. Brocksen*

Analysis of Residential Response to Time-of-Day Prices

EA-2380 Final Report (RP1363); $27.00

This report contains several related papers on modeling time-of-day electricity demands for the residential sector. Data from the Arizona and Wisconsin time-of-day pricing experiments, as well as (to a lesser extent) data from the Connecticut experiment and the National Time Allocation Study, were used in estimating a variety of empirical models of these demands. The contractor is the University of Michigan. *EPRI Project Manager: S. D. Braithwait*

EPRI Automated Telephotometer

EA-2386 Final Report (RP1630-10); $13.50

This report describes the development and field testing of a prototype automated telephotometer, a device for monitoring atmospheric visibility. This effort included the development of color discrimination capabilities and of computer software for the routine conversion of observed target and sky radiances into measurements of visual range, target color impairment, and target modulation depth (texture). The contractor is SRI International. *EPRI Project Manager: G. R. Hilst*

Load Management Strategy Testing Model

EA-2396 Final Report (RP1485); $13.50

This report describes the Load Management Strategy Testing Model, a computer code for use in demand-side planning. The model provides a quantitative framework for evaluating the costs and benefits of load management strategies, including time-of-use pricing, direct load control, and conservation. It is fully documented and user-tested. The contractor is Decision Focus, Inc. *EPRI Project Manager: E. V. Niemeyer*

Planning Workshop on Solute Migration From Utility Solid Wastes

EA-2415 Proceedings (RP1620-7); $13.50

A workshop to identify research needed to predict the fate of solutes released from utility solid wastes was held in Nashville, Tennessee, in November 1981. Participants represented the utility industry, the academic community, and government. They cited six major research activities necessary for the development of methods for predicting the release, migration, and attenuation of solutes. A recommended research plan is summarized in this report. The contractor is Science Applications, Inc. *EPRI Project Manager: I. P. Murarka*

Load Management: Issues, Objectives, and Options

RDS-100 Final Report; $15.00

This report summarizes the findings of the Rate Design Study, a nationwide load management research effort undertaken in response to requests by the National Association of Regulatory Utility Commissioners. The research was carried out by EPRI under the sponsorship of the American Public Power Association, the Edison Electric Institute, and the National Rural Electric Cooperative Association. The report examines load management policies, costing for ratemaking, load management equipment, customer perspectives, and cost-benefit analysis. *Executive Director: René Malès*

NUCLEAR POWER

Effects of Shutdown Chemistry on Steam Generator Radiation Levels at Point Beach Unit 2

NP-860 Interim Report (RP825-2); $9.00

A refueling shutdown chemistry test was conducted at Point Beach Unit 2 to study the relationship between shutdown chemistry and steam generator radiation fields. Detailed analyses performed on the reactor coolant samples taken during cooldown are described, and data are presented that correlate chemical and radioisotopic releases into the coolant with plant operation and coolant conditions during shutdown. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. A. Shaw*

Steam Plant Surface Condenser Leakage Study Update

NP-2062 Final Report (RP1778-1); $12.00

This project, a supplement to an earlier study on the reliability of steam plant surface condensers, addressed (1) condenser materials for which limited data were previously available, and (2) certain aspects of condenser design, operation, and maintenance to which considerable industry attention has been directed in recent years. Topics covered include condensers in cooling-tower service, the performance of titanium and AL-6X stainless steel tubes, the condenser drain collection system, and deaeration in condensers. The contractor is Bechtel National, Inc. *EPRI Project Manager: T. M. Law*

Effective Use of Plant Betterment Funds: Generation Availability

NP-2167 Final Report (RP1391-2); $15.00

This report presents analytic methods applicable to data generally available from electric power plants through their reports to NERC's Generating Availability Data System (GADS) and their in-house work order systems. It describes the use of the data and of availability engineering concepts to develop options regarding plant improvements, system planning, and new plant design and procurement. The report is designed as a practical guide to data usage in availability engineering. The contractor is The S. M. Stoller Corp. *EPRI Project Manager: J. M. Huzdovich*

Power Plant Availability Engineering

NP-2168 Final Report (RP1446-1); $42.00

This report presents the basic techniques of availability engineering and describes the application of probabilistic methodologies in this field. The fundamentals of probabilistic theory are reviewed, and a basic model developed to implement availability engineering in power plant design, construction, and operation is detailed. Many examples based on actual field experiences in availability engineering are presented. The contractor is Pickard, Lowe and Garrick, Inc. *EPRI Project Manager: J. M. Huzdovich*

SPEAR–BETA Performance Code System

NP-2291 Final Report, Vol. 1 (RP700-3, RP971-1, RP971-2); $19.50

This volume provides a general description of the SPEAR–BETA fuel reliability code system. The methodology employed and the structure of the code system are summarized. Details are provided on major system components: data preparation routines, the mechanistic fuel performance model, the mechanistic cladding failure model, and the statistical failure model. The contractor is Entropy Limited. *EPRI Project Manager: S. T. Oldberg*

Fluid and Thermal Mixing in a Model Cold Leg and Downcomer With Loop Flow

NP-2312 Interim Report (RP347-1); $21.00

This report describes a three-month series of fluid-mixing experiments performed at atmospheric pressure in a 1/5-scale transparent model of the cold leg and downcomer of typical PWRs. Facility geometry, instrumentation, and testing procedures are detailed. Data are presented in tabular and graphic form, and photographs of the mixing phenomenon that highlight the flow structure are included. The contractor is Creare, Inc. *EPRI Project Manager: K. H. Sun*

Component Development for Duplex Tube Steam Generator for Large LMFBR Plant

NP-2316 Final Report (RP1704-13); $15.00

This report presents the results of a project to develop technology for double-walled (duplex) tubes and the Foster Wheeler–type tubesheet for large LMFBR steam generators. Mechanically bonded duplex tubes fabricated under various manufacturing conditions were evaluated. The contractor is FW Energy Applications, Inc. *EPRI Project Manager: R. K. Winkleblack*

Solution Methods for Simulation of Nuclear Power Systems

NP-2341 Final Report, Vol. 1 (RP1381); $10.50

This volume (together with NP-1928) describes work performed from 1979 to 1981 to develop methods for reducing computer time and cost for the numerical solution of large nonlinear initial-value problems, with application to the dynamics of nuclear power systems. This work involved techniques for partitioning dynamic systems according to time-scale considerations and for solving dynamic equations by multirate integration methods. The contractor is the University of Arizona. *EPRI Project Manager: P. G. Bailey*

Liquid Carry-Over and Entrainment in Air-Water Countercurrent Flooding

NP-2344 Final Report (RP1160-1); $18.00

Countercurrent flows of air and water were studied experimentally under atmospheric conditions in single-tube and contraction-plate-in-tube test sections. The results are presented primarily in terms of liquid carry-over rates as functions of gas injection rates. The contractor is the University of

California. *EPRI Project Managers: Meir Toren and K. H. Sun*

TOAFEW–V Code and Library of 154-Group-Processed ENDF/B–V Fission-Product and Actinide Cross Sections

NP-2345 Interim Report (RP975-2); $10.50

This report describes the reduction of the extensive neutron data of ENDF/B–V to a more manageable data base useful for calculations with core physics, inventory (burnup), and summation codes like those of the EPRI ARMP collection. This was accomplished by processing the detailed cross-section representations with the NJOY code to produce thermal, resonance-integral, and 154-group values. The library of processed cross sections is furnished, along with a flexible cross-section collapsing code (TOAFEW–V). The contractor is the Los Alamos National Laboratory. *EPRI Project Manager: Odelli Ozer*

Instability Predictions for Circumferentially Cracked Stainless Steel Pipes Under Dynamic Loading

NP-2347 Final Report (RPT118-2); Vol. 1, $9.00; Vol. 2, $28.50

This report presents methods to predict margins of safety for circumferentially cracked type-304 stainless steel pipes that are subjected to applied bending loads. Volume 1 provides an overview of the technical approach, results, and conclusions. Volume 2 contains nine appendixes that detail the results. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: D. M. Norris*

Nonlinear Soil-Structure Interaction Analysis of SIMQUAKE II

NP-2353 Final Report (RP810-2); $13.50

This report describes a method of modeling soil-structure interaction for nuclear plants in earthquakes and its application to analyses of the SIMQUAKE II field test. The analytic approach can be used to simulate a three-dimensional structural geometry, nonlinear site characteristics, and arbitrary input ground shaking. The method incorporates STEALTH, an explicit finite difference code. The contractor is Weidlinger Associates. *EPRI Project Manager: H. T. Tang*

Water-Level Measurements Using Ex-Core Neutron Detectors at Farley Unit 1

NP-2354 Final Report (RP1611); $18.00

This report documents water-level measurement tests at Unit 1 of Alabama Power Co.'s Farley nuclear plant. Measurements were made during a normal plant outage by using an ex-core neutron detector system placed on top of the reactor vessel head. The system was able to indicate when the water level in the vessel approached to within approximately four feet of the top of the reactor core. Two-dimensional computer calculations simulating the experiment agree well with the measured data. The contractors are National Nuclear Corp.; Science Applications, Inc.; and Technology for Energy, Inc. *EPRI Project Manager: P. G. Bailey*

Nuclear Power Plant Perimeter Intrusion Alarm Systems

NP-2355 Final Report (RP1173-1); $24.00

This report presents the results of a study of nuclear plant perimeter security systems conducted to provide guidance to electric utilities for plant-specific application of various available systems or combinations of systems. Regulatory requirements and cost-effectiveness evaluations are considered. The contractor is E-Systems, Inc. *EPRI Project Manager: B. P. Brooks*

Human Factors Methods for Assessing and Enhancing Power Plant Maintainability

NP-2360 Final Report (RP1126-1); $28.50

This study—a follow-on effort to NP-1567, a human factors review of nine power plants with respect to maintainability—provides data-gathering tools for use by utilities in reviews of their own plants. These tools, which are applicable to both nuclear and fossil fuel plants, include an illustrated checklist; a structured interview; task analysis formats; communications, illumination, and safety surveys; and potential accident and damage analyses. Enhancement opportunities and strategies are discussed. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Manager: H. L. Parris*

Descriptive Evaluation of RELAP-5

NP-2361 Final Report (RP1938-2); $9.00

This basic hydrodynamic model chosen for the RELAP-5 code development effort is evaluated. The report examines the basic assumptions used in developing the field equations, the major process and constitutive models, and the numerical solution algorithm. Current applications of RELAP-5 are listed. The contractor is Practical Analysis & Computing, Inc. *EPRI Project Manager: L. J. Agee*

Marviken Full-Scale Critical Flow Tests

NP-2370 Final Report (RP956-1); 35 vols. (priced per vol.)

This report documents the full-scale critical flow tests performed at the Marviken power station in Sweden. The volumes can be divided into three groups. Volumes 1–3 are survey reports; Volumes 4–8 cover the test facility, measurement instrumentation, computer system, calculation methods, and data accuracy; and Volumes 9–35 present detailed results for each test. The contractor is the Marviken Project. *EPRI Project Manager: Avtar Singh*

Condenser Retubing Criteria Manual

NP-2371 Final Report (TPS79-763); $13.50

This report provides engineering assistance to utilities involved in retubing steam surface condensers with corrosion-resistant materials, such as titanium and the recently developed high-alloy pit-resistant steels. Engineering problems addressed are tube joint strength, roller expansion and flare, uplift forces on the condenser, vibration, and increased tubesheet and water-box corrosion. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: T. M. Law*

Model Pump Performance Program: Data Report

NP-2379 Interim Report (RP347-1); $27.00

A 1/20-scale model of a reactor coolant pump was tested under single- and two-phase flow conditions to obtain information on two-phase pump performance and flow regime effects throughout three quadrants of pump operation. Extensive data from low-pressure air-water and high-pressure steam-water steady-state tests, cavitation tests, and transient blowdown tests are presented. The contractor is Creare, Inc. *EPRI Project Manager: K. H. Sun*

Techniques for Efficient Storage and Retrieval of Industrial Radiographs

NP-2383 Final Report (TPS79-766-5); $12.00

This study investigated techniques to improve the efficiency of industrial radiograph storage and retrieval. The storage techniques considered were digital storage on magnetic disk or tape and analog storage on video tape, 33-mm film, or optical video disk. Image enhancement and data compression techniques investigated included optical image processing, analog signal processing of a scanned image, and digital enhancement and image coding techniques. The contractor is Science Applications, Inc. *EPRI Project Manager: M. E. Lapides*

Decentralized Data Systems: Results and Recommendations

NP-2384 Final Report (RP1319-3); $34.50

This report describes a survey of decentralized data systems that are potential sources for the information system for generation availability (ISGA), which is under development. It also examines methods of integrating such sources into ISGA. Details of the surveyed utility, industry, and regulatory decentralized systems are provided, along with a matrix of data elements and formats that allows a comparison of the systems. The contractor is the Southwest Research Institute. *EPRI Project Manager: J. M. Huzdovich*

Implicit STEALTH: Special Version of STEALTH for Low-Speed Fluid Flow Analysis

NP-2385 Final Report (RP965-5); $9.00

This report describes a version of the STEALTH computer code designed for the calculation of problems involving low-speed fluid flow. The version employs an implicit finite difference technique to solve one- and two-dimensional equations of motion for both incompressible and compressible fluids. The contractor is Science Applications, Inc. *EPRI Project Manager: H. T. Tang*

HITCH Computer Code: Chemistry and pH Estimates of Concentrating Aqueous Solutions

NP-2388 Computer Code Manual (RP404-1); $12.50

This manual describes the code HITCH, developed to calculate solution composition and high-temperature pH of faulted aqueous environments during concentration by high-temperature boiling. The code covers hydrogen, hydroxyl, ammonium, sulfate, bisulfate, bicarbonate, chloride, sodium, magnesium, and calcium ions, as well as ammonia and carbon dioxide. It is formulated in two versions applicable to steam generator waters. The bulk model applies to bulk water converted to steam as it rises in the steam generator. The isolated-cavity model applies to solutions in heated crevices. The contractor is NWT Corp. *EPRI Project Manager: C. E. Shoemaker*

Turbine Chemical Monitoring at ANO-1

NP-2390 Final Report (RP1124-4); $15.00

Trace contaminant chemistry was characterized throughout the secondary system at Arkansas Nuclear One Unit 1 (ANO-1) during normal and transient operation as part of a project addressing low-pressure turbine corrosion. Because of the low-contaminant concentrations during normal operation, ion-exchange preconcentration techniques were employed over sampling periods of several days at up to 10 sample locations simultaneously. Impurity mass transport relations were developed, with emphasis on sodium, chloride, sulfate, iron, and copper. The contractor is NWT Corp. *EPRI Project Manager: T. O. Passell*

Secondary-System Water Chemistry Program for ANO-1

NP-2391 Final Report (RP1124-3); $18.00

Trace impurity monitoring of the steam and water from various points around the secondary system at ANO-1 during full-power operation and during a cooldown is described, and characteristics of once-through steam generators are highlighted. Preliminary plant studies, equipment and procedures, sample analysis, and data analysis are detailed. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: T. O. Passell*

Multidimensional Thermal-Hydraulic Reflood Phenomena in a 1692-Rod Slab Core

NP-2392 Interim Report, Vol. 1 (RP1118-1); $10.50

This report presents the results of an examination of the physical processes governing the thermal-hydraulic reflooding behavior of a multipin PWR bundle. It describes the experimental apparatus and reviews the test runs, which used varying initial rod temperatures, reflood rates, and subcooling temperatures. Multidimensional aspects of flow distribution are discussed, and heat transfer data are provided. The contractor is the University of California at Los Angeles. *EPRI Project Manager: R. B. Duffey*

Chemical Impurity Monitoring in the Turbine Environment at ANO-1

NP-2397 Final Report (RP1124-1); $10.50

An overview is presented of three independent investigations of trace impurities in the secondary-side water and steam of ANO-1, a PWR with a once-through steam generator. Monitoring took place in 1978–1979 between two turbine-disk-cracking incidents. Measurements were made near the point of first condensation in the low-pressure turbines; emphasis was placed on sodium, chloride, and sulfate. The primary source of contamination was found to be the condensate polishing system. The contractor is NUS Corporation. *EPRI Project Manager: T. O. Passell*

Analysis to Predict the Shapes of Growing Stress Corrosion Cracks in BWR Piping Welds

NP-2399 Final Report (RPT118-7); $12.00

A model was developed to predict the shape during growth for stress corrosion cracks in BWR piping, with emphasis on large-diameter recirculation piping. The results of sensitivity studies performed with the model are presented. It was found that for the ranges of variables examined, the primary influence on crack shape is stress distribution. Somewhat smaller effects result from the absolute stress magnitude and from changes in growth kinetics and in initial flaw geometry. Life-time-to-failure estimates were also made, and the way each variable affects this parameter was examined. The contractor is Aptech Engineering Services. *EPRI Project Manager: R. L. Jones*

High-Temperature Thermodynamic Data for Species in Aqueous Solution

NP-2400 Final Report (RP1167-1); $16.50

This report summarizes the results of experimental and theoretical research on the high-temperature thermodynamic properties of aqueous species important to nuclear reactor water chemistry. Methods of predicting thermodynamic functions are presented for electrolytes up to 300°C for use in supplementing experimental data. The report includes tables (up to 300°C) of (1) important equilibrium constants for 78 reactions encountered in corrosion and precipitation in nuclear reactors, and (2) free energy functions for 56 individual species. The contractor is San Diego State University Foundation. *EPRI Project Managers: Daniel Cubicciotti and T. O. Passell*

Turbine Chemical Monitoring at ANO-1

NP-2404 Final Report (RP1124-2); $13.50

A project to assess steeple and disk rim cracking at ANO-1 is described. The report summarizes ANO-1 and its history, the secondary ion mass spectrometry analysis of cracked disk steeples, the continuous analysis of steam and water, and three grab sampling studies. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: T. O. Passell*

BWR Environmental Cracking Margins for Carbon Steel Piping

NP-2406 Final Report (RP1248-1); $31.50

Results are presented from a three-year experimental program comprising fatigue tests, constant extension rate tests, constant load tests, and electrochemical studies of plain carbon steel specimens in a range of high-temperature oxygenated water environments. The combinations of loading, temperature, and dissolved oxygen content leading to pronounced, environmentally assisted cracking effects are identified, and two approaches are outlined for providing additional margin for environmental degradation in carbon steel piping design. The contractor is General Electric Co. *EPRI Project Manager: R. L. Jones*

PLANNING AND EVALUATION

Technical Assessment Guide

P-2410-SR Special Report; $10.00

This guide was compiled for the use of EPRI staff and contractors to provide a common basis for evaluating electric energy R&D alternatives. The guide has two sections. The first presents a brief summary of the economic methodology (the revenue requirement technique), data on fuel price projections, and cost and performance information on transmission and generation technologies. The second presents a more complete explanation of the methodology and a series of sample problems. *EPRI Project Manager: George Applegren*

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