On-Line Monitoring

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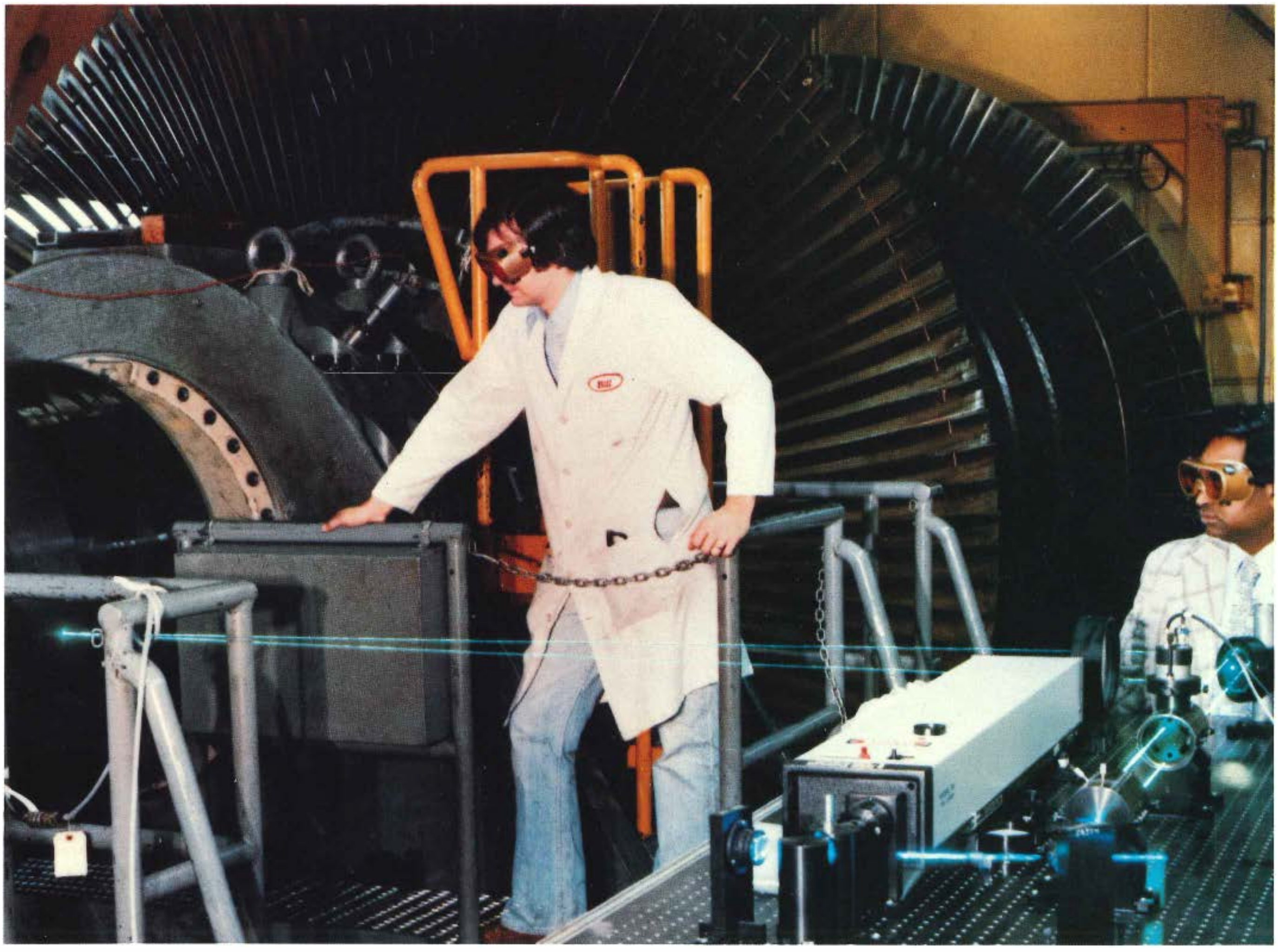

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Cover: Under development by power plant diagnosticians, laser light is a clinical probe that can detect torsional vibration in a spinning turbine shaft.

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Cool Water: Innovation in Financing and Management

The Cool Water coal gasification project, featured in this issue, involves not only a significant new power system development but also an innovative, exemplary approach to project financing and management. In this cooperatively funded project, the interests of the utility (Southern California Edison Co.), the process developer (Texaco, Inc.), the engineering contractor (Bechtel Group, Inc.), and a major manufacturer (General Electric Co.), are combined to share in project financial risks with other key interested parties, namely, EPRI, the Japan Cool Water Program Partnership led by Tokyo Electric Power Co., and Eseerco. Totally financed by the private sector, Cool Water could become a model for future funding of expensive, first-of-a-kind demonstrations of new technology on a meaningful scale.

The approach is certainly consistent with the Reagan Administration's view of the role of the private sector in energy R&D. The modular character of coal gasification–combined-cycle systems has allowed total project demonstration costs to be held to $300 million, still within the capacity of the private sector to finance. Larger power systems in the range of hundreds of megawatts or even gigawatts would probably require financial participation by the federal government, with the likelihood of decreased project control by the private sector.

Even though funding is now secure, the project went through a difficult period in 1981. The project was saved only through a major increase in the EPRI funding commitment made by the Board of Directors in December 1981. This increased financial role in Cool Water has placed a major responsibility on the EPRI staff to achieve our development/demonstration objectives at an acceptable cost. Our recent review of cost factors indicates that we have a good chance of completing construction within or below our present obligation. The EPRI staff, along with our Cool Water partners, are committed to achieving this end. This common objective is perhaps more pronounced in Cool Water than in other projects because there is a firm incentive for all the partners and contractors to control costs: we will all share the burden of overruns. There is nothing like having a ''stake in the game'' to ensure cost control.

Further, the participatory nature of the project allows the common interests of the international community to come together in developing a new technology. Our Japanese partners have also weathered some difficult periods and yet have remained resolute. We are proud of their affiliation with the project and of the personal relationships that have grown from our mutual interests. We hope that other countries will find participation in Cool Water to be in their interests and will recognize it as a cost-effective way to further their understanding of a new, emerging technology. We also expect that additional domestic companies will share in the Cool Water project.

Indeed, Cool Water is an innovative financing and management experience. Its success may well be the bellwether in the future of joint technical development by the private sector. The U.S. electric utility industry can be proud of the unique and powerful role it has played in this experiment.

Dwain F. Spencer

Dwain F. Spencer, Director
Advanced Power Systems Division

Authors and Articles

Doctors depend on medical histories of normal organic function as a basis for diagnosis and treatment when some function departs from normal. **Diagnostic Monitoring of Plant Components** (page 6) reviews how researchers are taking the same approach with on-line sensors and computers to predict machinery maintenance needs. Ralph Whitaker, the *Journal's* feature editor, developed the article from the work of R&D managers in three EPRI divisions.

Anthony Armor came to the Coal Combustion Systems Division in September 1979 after 11 years with General Electric Co., where his work in advanced mechanical engineering for large turbine generators culminated in management of a development program on superconducting generators. Armor previously was a professor at two polytechnic colleges in London, teaching mathematics (3 years) and acoustics, vibrations, and fan engineering (3 years). He earned BS and MS degrees in mathematics and mining engineering, respectively, at the University of Nottingham.

James Edmonds joined the Electrical Systems Division in November 1978, after a short period with the Department of Energy, where he managed research projects on energy storage and planned a program of rotating electrical machinery research. He was with American Electric Power Service Corp. between 1968 and 1977, ultimately as staff electrical engineer with responsibility for all rotating electrical machinery on the AEP system. Edmonds is a 1968 electrical engineering graduate of the University of Illinois.

Gordon Shugars has been with the Nuclear Power Division since September 1977, specializing in machinery monitoring systems. He was formerly with Bechtel Power Corp. for three years, holding field and office positions in the design, construction, and test of power plants. Earlier, Shugars was in the Navy for five years, most of that time on assignment to the AEC Division of Naval Reactors. His work involved reactor safety analysis and design for operability and maintainability. Shugars holds BS and MS degrees in electrical engineering from the University of Illinois.

■

Increasing the time that maintenance people can work in high-temperature areas of power plants is no small trick. Nadine Lihach, senior feature writer, tells how it can be done in **Keeping Cool on the Job** (page 14). The article reports on R&D managed by John O'Brien of the System Performance Program in EPRI's Nuclear Power Division.

A specialist in human factors engineering, O'Brien has been with the Institute since November 1979. He previously worked for Westinghouse Electric Corp. for five years, engaged in man-machine studies at the company's R&D center. O'Brien is a graduate of North Carolina State University with BA, MS, and PhD degrees in industrial and engineering psychology.

■

Gasification of coal isn't new. Neither is the gas-fueled combustion turbine, nor the steam turbine that can be added for better thermal efficiency in driving electricity generators. But when they are all merged in a single plant, a new power technology emerges. To explain this kind of system integration in **A New Path From Coal to Electricity** (page 18), Ralph Whitaker, *Journal* feature editor, was aided by Thomas O'Shea, EPRI's project manager for the Cool Water demonstration plant now under construction.

O'Shea has been with EPRI's Advanced Power Systems Division since August 1977, all but one year of that time managing the Institute's technical and coordinating role in the Cool Water project. For 12 earlier years, O'Shea was with Caltex Petroleum Corp., beginning as a power and utilities engineer and becoming an engineering superintendent during a succession of process design and refinery construction assignments in Australia, the Philippines, and Bahrain. He is a 1965 electrical engineering graduate of Illinois Institute of Technology.

■

Computer networks are now putting more scientific and technical information into the hands of more people, in more places—and faster—than ever before. **Information at Hand** (page 26) traces the development of worldwide networking that now includes the Electric Power Database compiled by EPRI. Science writer Mary Wayne turned to EPRI's manager of Information Centers for article background.

Donald Black joined the Institute in March 1982, coordinating the distillation and organization of R&D information in


O'Shea


Black

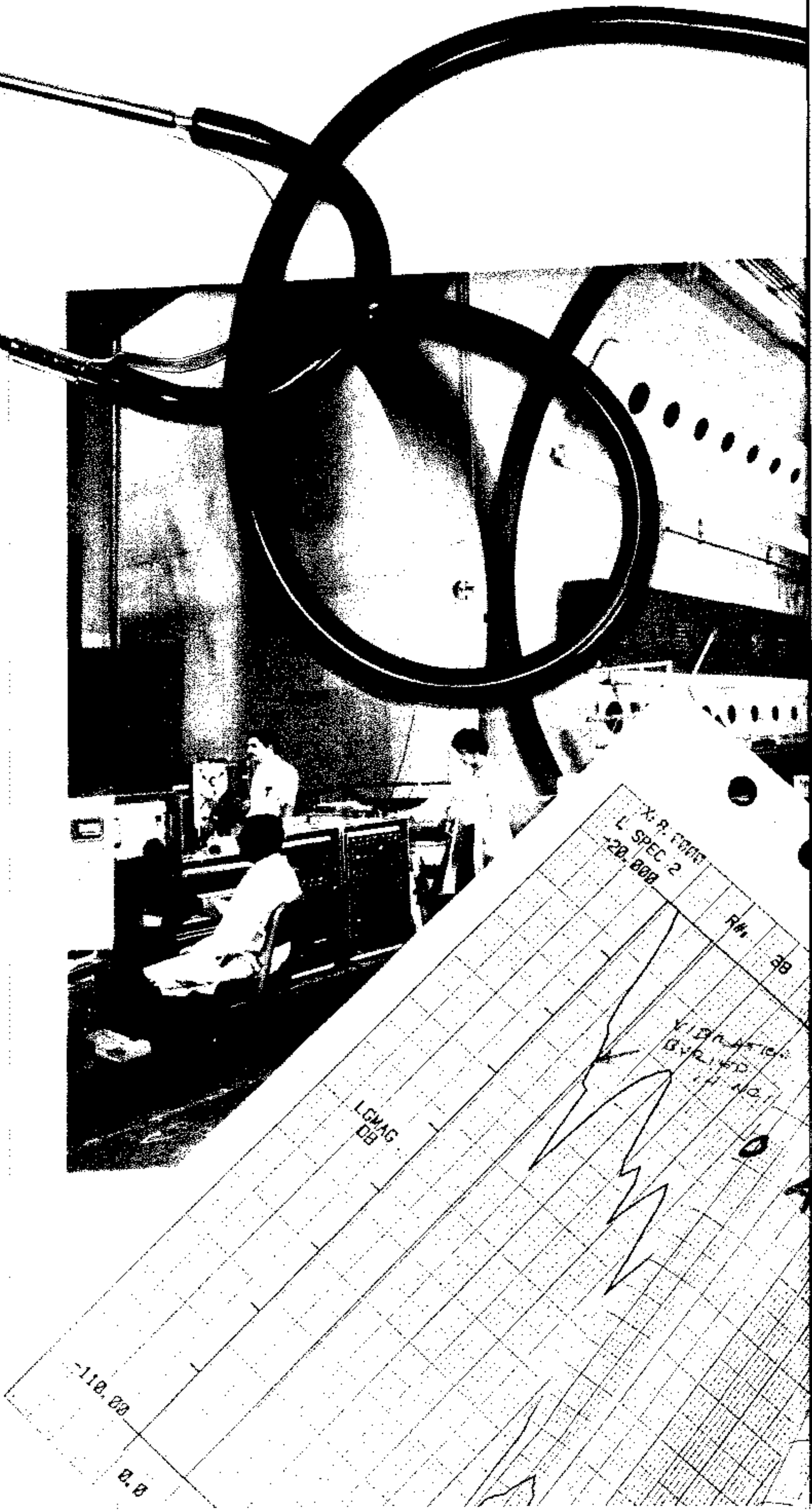

Shugars

Edmonds


O'Brien

several forms: EPRI's library, catalogs of project abstracts, subject indexes, computer input data, and even brief summaries for response to telephone inquiries. Before joining EPRI, Black was with System Development Corp. for 15 years, developing and applying methods to organize and retrieve information. He was earlier a science librarian and consultant at two campuses of the University of California. Black graduated from the University of California at Berkeley in library science in 1952.


Armor



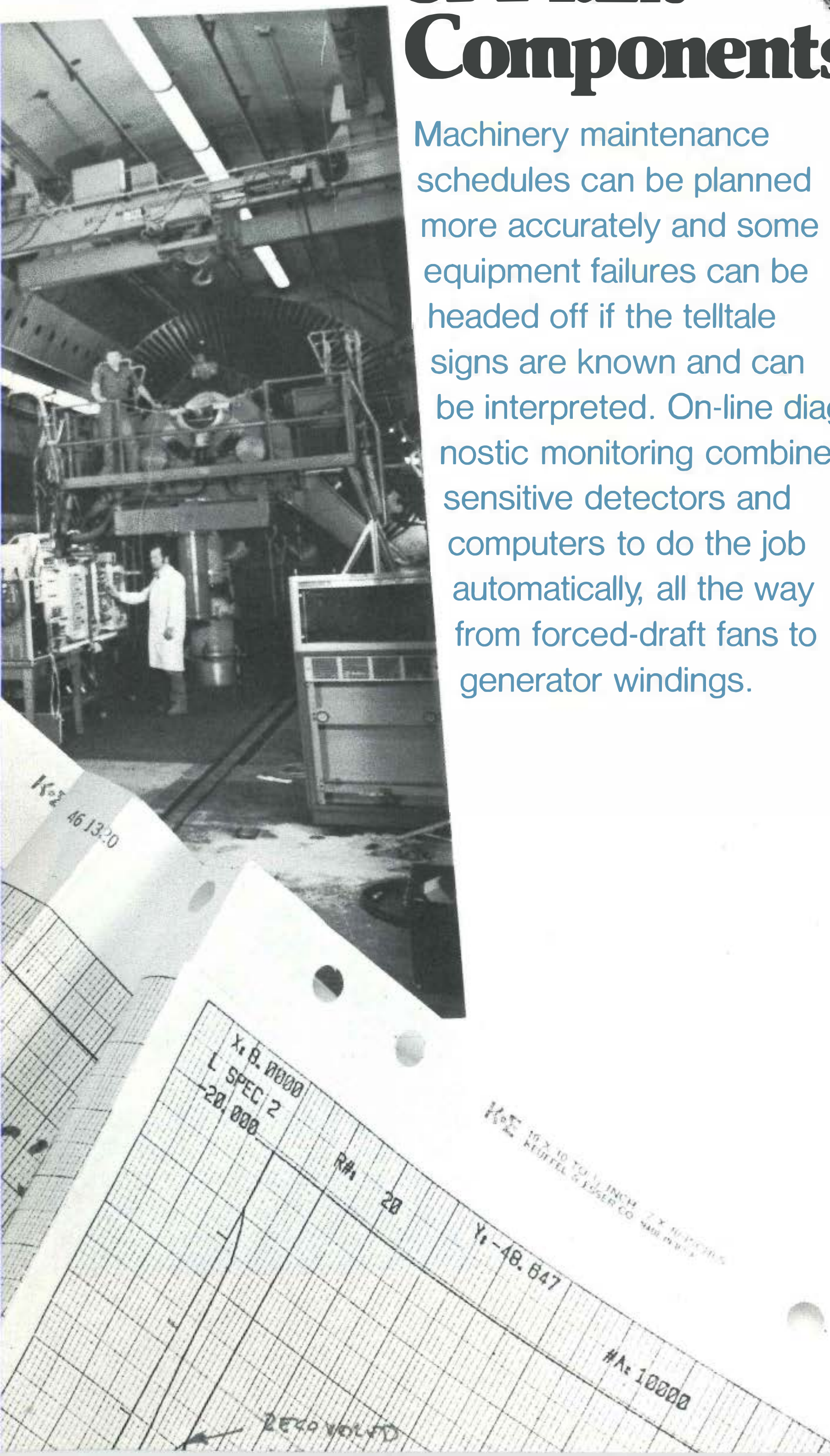
Conscientious health care has long called for periodic checkups at the doctor's office. The routine is familiar: height, weight, and temperature; pulse and blood pressure; the sound of your heart—even the sound of your voice and the slight cough that may interrupt it.

Today the move is toward health maintenance as a continuous personal responsibility. For example, you're encouraged to buy your own blood pressure cuff or to patronize the coin-operated instruments that are beginning to appear. The point is, more frequent measurements yield a more thorough basis for comparison and early diagnosis if some function departs from the norm, even when you feel fine.

Incipient machinery failures in power plants can be diagnosed this way too, and researchers are developing the instruments to do the job. A computer program directs frequent samplings of information from specialized sensors, compares findings with stored data on normal component behavior, and produces maintenance and repair advice before a problem becomes acute. This automated procedure for detecting and analyzing machinery maintenance requirements is called diagnostic on-line monitoring.

As in medical practice, many specialized sensors have been devised to detect symptoms in ailing machinery. For example, the vibration patterns of normally running pumps and turbines are so distinctive they are considered to

Diagnostic Monitoring of Plant Components



Machinery maintenance schedules can be planned more accurately and some equipment failures can be headed off if the telltale signs are known and can be interpreted. On-line diagnostic monitoring combines sensitive detectors and computers to do the job automatically, all the way from forced-draft fans to generator windings.

constitute individual signatures. Vibration signature analysis, in fact, is the best known and developed on-line monitoring technique, but others have also emerged as R&D topics in the past half-dozen years, and a few have already been carried to commercial practice.

One technique is the detection of high-frequency electromagnetic radiation that is generated by unwanted actions in electrical apparatus. Another is by optical means (including fiber conduits and laser beams) to measure mechanical and thermal properties of equipment. A third is the sensing of acoustic emissions, both the spontaneous ultrasonic pulses that signal microcracking in a material and the subtle ultrasonic hiss of minuscule high-pressure leaks. Yet another monitor relies on the mass spectra of tracer gases.

Each of these techniques is valuable because it gets at a certain kind of phenomenon. Optical monitoring is additionally attractive because it is totally nonintrusive: there is no hardware to interfere with normal machinery operation, no tacked-on sensor, itself subject to wear and tear. Continuous acoustic emissions from fluid flow may mean that a valve is leaking and must be repaired now or that another boiler tube has sprung a leak and must be plugged next month; but separate acoustic bursts from a metal are true precursor phenomena, signaling stress damage well before it progresses to a functionally significant degree.

Predicting maintenance

Diagnostic monitoring addresses the maintenance actions that make for a longer and more productive power plant life. One key to productivity is higher availability. Availability is measured in two ways.

In its simplest meaning, availability is a historical time measure: the percentage of time in which a power unit could or did run at any fraction of its full capacity, thereby generating some amount of energy and revenue. Availability is important to plant operators and dispatchers, telling them the true percentage of calendar days and clock hours when a unit was able to serve load. Only a complete shutdown reduces availability.

Equivalent availability is a contrived time measure. It is a lower percentage because the actual time run is translated into the lesser time that would have been needed to generate the same amount of energy if the unit had run at full capacity. Equivalent availability is a stronger signal to maintenance groups because any malfunction that limits unit output, however slightly, reduces the equivalent availability figure.

For nuclear plants, revenue to recover high capital costs is a strong incentive for monitoring maintenance needs. Because nuclear fuel and operating costs are low, the plants are preferred for steady baseload service. But they must actually be available if they are to be chosen; they must produce energy if their economy is to be realized.

For fossil fuel plants, the rationale for monitoring is somewhat different. These plants predominate in number and overall generating capacity across the nation. Moreover, many of them are nearing the end of their planned lives. If monitoring can ensure continued safe operation and define the maintenance to keep them running longer, new plant investment can be postponed. The costs of the monitoring and the maintenance are far preferable to the cost of a new plant at today's prices.

Diagnostic monitoring in any kind of power plant should reduce the incidence of forced outages, the unplanned derating or shutdown of a unit caused by malfunction. In addition, advance information from plant monitors should enable needed spare parts or specialized services to be ordered ahead and be on hand when needed. Not only is the maintenance itself done more efficiently and at less cost, but the high costs of replacement energy are held to the shortest possible time.

There are secondary benefits from diagnostic monitoring. One is safety verification, a special concern of the highly regulated operation of nuclear power plants. For example, NRC now calls for periodic inspection and performance checks on pumps in reactor safety systems, entailing the use of worker allotments of radiation exposure. With experience, diagnostic data from on-line monitoring may prove a cheaper way to fulfill this regulatory requirement.

Diagnostic monitoring will also influence the design of new power plant equipment as data drawn from experimental work are fed back to manufacturers and their design staffs.

EPRI's research managers are quick to distinguish diagnostic monitoring from performance monitoring. "It's a matter of purpose," says Anthony Armor of the Availability and Performance Program in the Coal Combustion Systems Division. "Many of the meters, gages, and counters in a power plant are guides for meeting the design conditions for efficient operation." As Armor sees it, "Performance monitoring looks at the plant process and its efficiency—with an eye for safety, of course. Diagnostic monitoring looks at the plant equipment and its operability—with an eye toward what service will be needed and when."

Gordon Shugars works in the Chemistry, Radiation, and Monitoring Program of the Nuclear Power Division. He draws an example from his R&D experience with the Millstone power plant of Northeast Utilities in Connecticut. "Some monitors serve both purposes," says Shugars. "The vibration spectrum of a feedwater pump at Millstone had a bad spike at one frequency. As a performance monitor," Shugars points out, "the data told the plant operator to adjust the flow through the pump, and it indicated when the adjustment was sufficient. But as a diagnostic monitor, it also told what to fix at the next outage and what parts would be needed."

Pinpointing outage causes

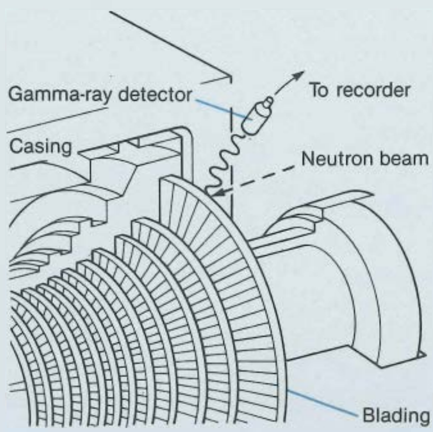
Like a wide range of other R&D to improve fossil fuel plant operation, EPRI's work in diagnostic monitoring responds to a distressing downward trend in reliability that has been noted across the utility industry since the mid-1960s. The average equivalent availability of coal-fired units of 400-MW and larger capacity, for example, declined from about 77% in 1968 to about 67% in 1977, just 10 years later.

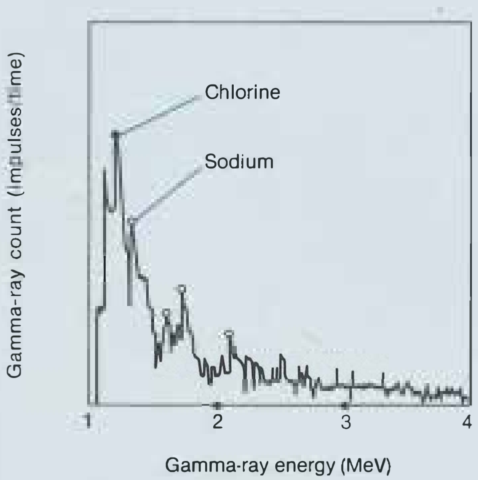
Not surprisingly, when EPRI dissected the records of lost availability, many root causes were revealed that do not, in and of themselves, force a unit shutdown, a total outage. Boiler tube leaks are an example, tolerable at the expense of additional fuel, more makeup feedwater, vapor in the plant exhaust plume, and reduced equivalent availability.

"Ultimately," says Armor, "waterwall and superheater tubes in coal-fired boilers are, on a nationwide basis, the first and second most important causes of plant downtime. More than 80% of such outages are forced, and they represent some four percentage points of lost availability, having an annual value of more than $500 million."

At the other extreme from frequent and annoying boiler tube leaks are rare catastrophic failures in power plants, the outright breakage of a component that causes major destruction of other equipment and momentarily creates danger to plant personnel. The classic example is a broken turbine disk or burst rotor.

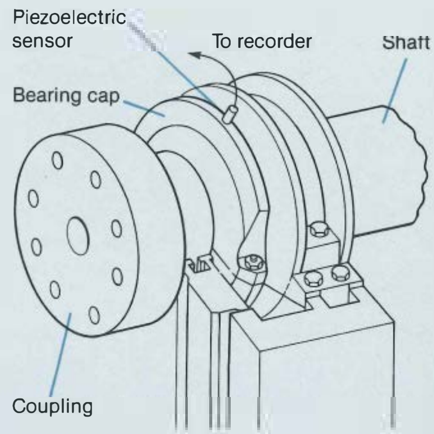
Aside from the human hazard, the in-

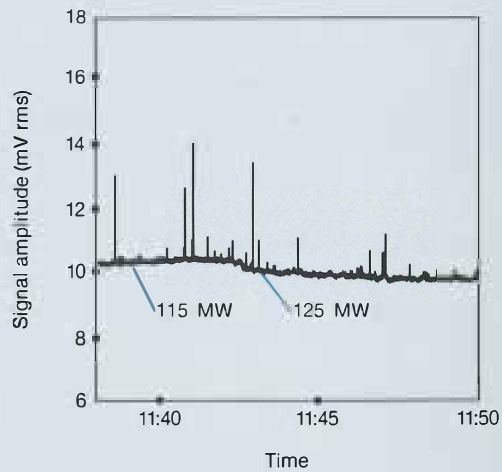




TURBINE BLADE CORROSION

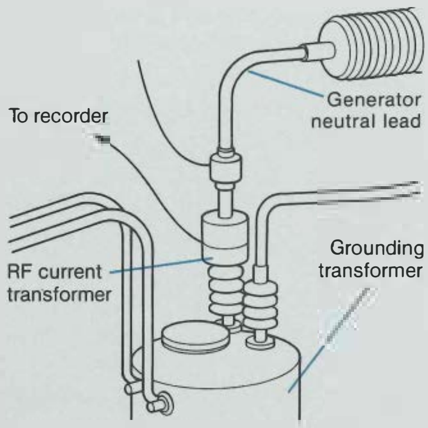
Sodium chloride on turbine blades is revealed when gamma-ray impulses are triggered by neutron bombardment. Peaks are at the energy levels characteristic of sodium and chlorine. Rate of corrodent buildup is the basis for scheduling inspection and cleaning.

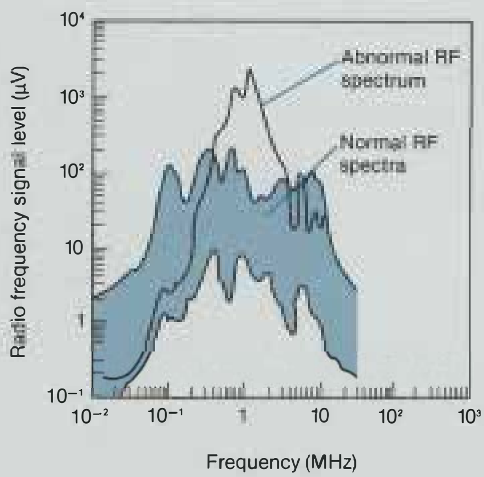




TURBINE SHAFT CRACKING

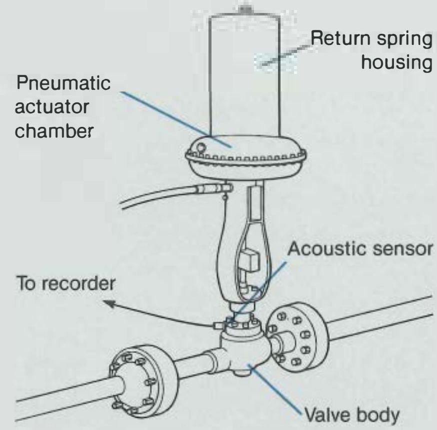
Spikes of acoustic energy denote extremely small, intergrannular dislocations—the origins of cracks—in the turbine shaft, caused by thermal shock or momentary torque or accumulated fatigue. Levels and frequencies shown here are normal and have no effect on the functional integrity of the shaft.

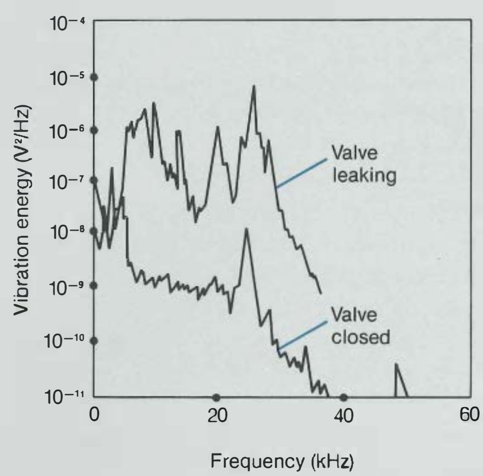




GENERATOR ARCING

Broken stator wires make and break contact as the rotor turns, and the consequent arcing shows up as excessive RF signal intensity. Unless windings are repaired, the danger is an arc hot enough to sustain itself and fuse windings all the way around the generator.





VALVE LEAKAGE

Noise level for a leaking pressurizer relief valve is two orders of magnitude greater than background level when the valve is seated. Noise rises another two orders when the valve is open. Signals thus tell whether the valve needs to be isolated.

evitably long repair interval (months, at least, sometimes more than a year) and the prices of entire pumps and turbines easily justify R&D on monitoring techniques that can reliably pinpoint the source and trace the progression of the microcracking that must precede eventual failure.

By far the majority of mechanical problem phenomena fall between the extremes of tube leaks and rotor bursts. Their nature—vibration, fatigue, leak, shock, overheating, fouling, arcing, for example—is largely evident by their location. Of special concern in fossil fuel plants are forced-draft and induced-draft fans, pulverizers and primary air fans (in coal-fired plants), electrostatic precipitators, and flue gas scrubbers.

In nuclear plants, steam generators are high on the list because of tube leaks, just as in fossil fuel boilers. Valves are another item, especially safety and relief valves in BWR plants and feedwater control valves in the secondary loop of PWR plants. Valve vibration and wear are one factor here. Another is valve position; as a safety matter, monitoring can detect if a valve is open or closed and if it is leaking.

In power plants of any kind there are many analogous and similar components, notably turbines and generators, but also feedwater heaters and a great variety of auxiliary pumps and drives. Steam condensers are a major and acknowledged source of cooling-water inleakage, but they are a difficult target for monitoring because of the small pressure differential between coolant and condensate. Leakage flows are not distinctively noisy to any economically feasible sensor.

Diagnosis from plant data

The first EPRI project to reach the hands-on monitoring stage was begun in 1976 under Coal Combustion Systems Division auspices. The setting was the Brayton Point station of New England Power Service Co., where Rockwell International Corp. spent more than two years gathering vibration and ultrasound signals. Armor recalls that the project monitored most of the accessible equipment—boilers, pumps, fans, turbines, generators, and other machinery.

For the multifrequency vibrations transmitted from each monitored component, computer analysis produced a complete characterization, showing signal amplitudes and energy intensities throughout the spectrum recorded. This signature remained in memory as a reference. Monitoring thereafter entailed periodic sampling of selected frequency intervals for comparison with the baseline signature and measurement of changes.

Not all acoustic emissions are continuous phenomena. Leaks are heard against the reference noise of flow in a tube or pipe, but the noise of microcracking is a sporadic occurrence. The Brayton Point work monitored acoustic emission counts under various operating conditions for bearings, turbine shafts, and boiler waterwalls.

In this initial wide-ranging effort, the main objective was to record instances of mechanical problems or failures. Secondarily, it was expected that hindsight, plus analysis of the data surrounding those occasions, would produce some predictive capability. As an example, vibrations of a boiler feed pump turbine (and the inboard pump bearing) showed intermittently increased intensity in the 3–26-kHz range for several months. During an outage, the coupling was found to have been rubbing; and after repair, there was a marked drop in vibration amplitude at all frequencies.

Research toward a predictive maintenance system for rotating machinery is being furthered by two of Armor's projects. Both efforts feature vibration signature analysis. At the New Haven Harbor plant of The United Illuminating Co., data have been taken to establish a strong statistical base relating normal vibrations to such variables as load, speed, pressure, and temperature. Analytic programs using this base have yielded vibration patterns that correlate closely with observed patterns from plant machinery in regular operation.

New research at Philadelphia Electric Co.'s Eddystone plant will carry the work a step further, seeking to model rotating machinery so that vibrations measured at one point on a shaft can be used to predict behavior at another.

Finding new correlations

Feedwater control valves have been a special target of Nuclear Power Division research guided by Shugars. A two-pronged effort by Technology for Energy, Inc., involved modeling the hydrodynamic behavior of valves and then monitoring vibrations in valves at three nuclear plants. The objective was to confirm model predictions of vibration modes.

In one instance, a model predicted valve resonance at 15 Hz under certain flow conditions. Monitoring revealed the precise behavior, which was rotary vibration of the valve stem that threatened to destroy the diaphragm of its pressure-driven actuator. Tighter stem packing, short of inhibiting valve action, was employed as a partial remedy. Analysis later showed that a detail of the internal shape of the valve was influencing flow dynamics, in turn setting up resonant vibration in the valve stem.

Not all the research relies on known relationships. Asked for an example of a problem for which there is yet no monitor, Shugars cites stress cracking in turbine disks, close to the roots of blades. "There is some thinking that we'll be able to infer it from the vibration patterns of blade tips. It's like a loose tooth that wiggles. If disk cracking progressively loosens the blade at its root, then the vibration frequency at its tip should change."

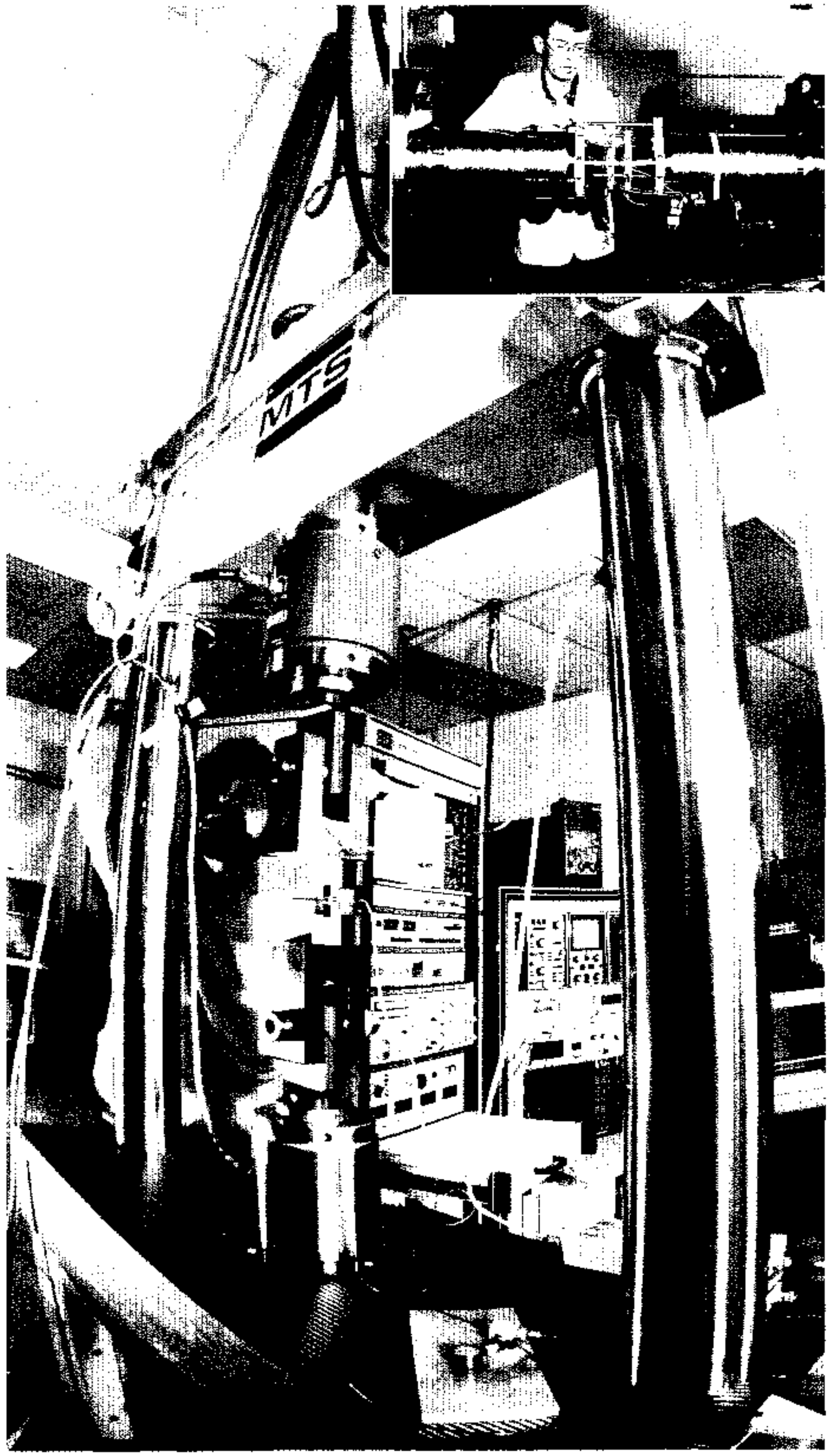
Failures of turbine blades themselves account for some three percentage points of lost availability, and they lead to other damage that causes unit outage. But any monitor of blade vibrations in a turbine will have to be very rugged or nonintrusive. Acoustic Doppler measurements may be feasible. The Doppler concept recognizes that pressure pulses generated by a vibrating blade have a higher apparent frequency as the blade approaches the sensor and a lower apparent frequency as it recedes. Changes in such a pattern while other conditions remain the same could indicate the formation and growth of a crack. This method is being pursued by the Franklin Research Center for the Coal Combustion Systems Division.

Electric oscillations

The first diagnostic monitor to come from EPRI research alone is a system that detects arcing inside a generator. The arcing may be in the stator windings, where wires break and thereafter flex open and closed under the tremendous electromagnetic forces of each rotor revolution; or the arcing may occur at progressive flaws in insulation. In either case, it gives rise to a changed radio frequency signal on the generator neutral, which can be sensed by a current transformer, recorded, and converted to an alarm when programmed values are exceeded.

EPRI's research, managed by Shugars, has been adapted by Westinghouse Electric Corp. in a commercial monitor, which was acknowledged last year as one of the 100 most important new industrial products by *Industrial Research & Development.* At least one utility has used EPRI's findings as the basis for developing its own system to monitor related phenomena as well, such as corona discharges on the surface of fan blades. The next step, a project of the Rotating Electrical Machinery Program in EPRI's Electrical Systems Division, will be to refine the monitor's discrimination of frequencies and their trend and meaning with time.

James Edmonds, project manager, points out that torsional shocks on generator shafts can result from electrical circuit phenomena on a utility transmission system far removed from the



Just as clinical records provide the basis for medical diagnosis, mechanical laboratory tests provide the data base for monitoring of power plant machinery. Tensile and torsional test specimens of various steels are fitted with sensors to obtain reference signals at different stress levels.

power plant. For example, line faults activate circuit breakers, and the subsequent high-speed reclosings of the breakers can create an electrical disturbance at the generator. The resultant stress may gradually fatigue the shaft. Another instance of torsional vibration can arise when electric oscillations of a very long line match and reinforce the natural resonant frequency of a generator shaft. This circumstance can break the shaft.

R&D for EPRI by General Electric Co. is intended to build an understanding of these system interactions that will be applicable anywhere in the United States. Utilities will participate in the research by installing monitors to sense, measure, and analyze relevant electric phenomena on their systems. For system planning and maintenance analyses, they will use a shaft torsional model and fatigue life data base compiled from earlier EPRI-sponsored laboratory work with a range of shaft materials, geometries, speeds, and torques.

Application outlook

The scope of these monitoring developments by three EPRI technical divisions ranges from a completed system, through adaptations of existing sensors, to the conception of new detection techniques and signal correlations.

Vibration signal analysis is the one complete here-and-now monitoring method. Vibrations are pervasive; frequencies are in ranges available to sensors that have a long history of development and use; and the root-cause phenomena are well known and documented. Recent R&D has been mainly that of quantifying time-to-failure data for various operating conditions, adapting data to computer manipulation, and devising automatic programs for sampling and analysis.

Optical sensing, including laser Doppler techniques, is probably five years from reality, other than in experimental and development applications. The detection devices themselves are evolving rapidly. Major work is still to be done in defining the detectable phenomena and their correlations with equipment maintenance requirements.

Acoustic emission monitoring, despite its importance to the high-priority problems of boiler and steam generator tube leaks, is not yet ready for that application. Armor estimates five years to commercialization because of the subtlety of the signals produced by small, high-pressure leaks and the virtual forest of possible sites to be surveyed in any single piece of equipment.

Monitoring of the acoustic energy bursts emitted from materials under stress is perhaps 10 years from routine use, but its progress benefits from acoustic emission analysis as a non-destructive examination method for pressure vessels and their welds. There is a great variety of materials and environments of potential interest, and correlations will not be easy, particularly as some applications require integration (in effect, triangulation) of data from several sensors as a means of locating the exact emission source.

Specifications for systems

The key attributes of all diagnostic monitoring are automatic control and on-line application. Computers are the single item that makes monitoring possible, once the detection and interpretation methods are worked out. Armor observes, for example, that power engineers have long known the meaning of certain frequency peaks in vibration signals. "In a fossil turbine, a 25–30-Hz peak is quite possibly created by oil whip. The oil film in the annulus between a shaft and bearing moves at about half the shaft speed. In some unstable conditions, the velocity of the oil causes it to generate cyclic forces on the shaft—vibrations."

Picking up on the example, Shugars says, "The big development is being able to do the diagnosis automatically instead of handing two spectrum prints to an expert, who overlays them against the window to make his observations, interpretation, and recommendation. What we're beginning to do now," concludes Shugars, "is to put the diagnostician into the computer."

The goal of EPRI's work is to produce monitoring system specifications for various applications. Each such specification would include the requirements for the sensor, a data base for the phenomenon, the software for monitoring and analysis, and the procedural instructions for a user. If experience to date is any indication, some such compilations will be the basis for monitoring system packages sold by manufacturers, and some would be adapted directly by utilities to their own one-of-a-kind needs.

Early conjecture that utility industry suppliers would consider monitors as a criticism of original equipment quality has not been borne out. A more real concern for EPRI's Armor, Edmonds, and Shugars is to ensure that planned R&D does not overlap what is already being done by a manufacturer.

The range of monitoring possibilities is considerable, but this is not to imply that everything in a power plant will eventually be continuously monitored. Shugars points out that the critical nature of some functions means that redundant equipment is already in place; and for such instances periodic monitoring, spot checks weeks or months apart, should be sufficient. Other components are essentially trouble-free anyway; monitoring would not be cost-effective.

For now, the needs for greater power plant life and availability are obvious, and the role of maintenance prediction is clearly seen. Utility design, operations, and maintenance engineers know they have problems that can be pinpointed by diagnostic on-line monitoring; they are knocking on R&D doors to get help. ■

This article was written by Ralph Whitaker. Technical background information was provided by Anthony Armor, Coal Combustion Systems Division; James Edmonds, Electrical Systems Division; and Gordon Shugars, Nuclear Power Division.

KEEPING COOL ON THE JOB

In the hot, humid atmosphere of a nuclear power plant, maintenance workers can become overheated well before radiation limits are reached. EPRI has evaluated personal cooling concepts for longer stay-time and greater efficiency.

A two-part frozen-water garment developed by EPRI is one good way to keep maintenance workers cool in the high temperatures of a nuclear plant. Ice-filled plastic packets are tucked into pockets of the inner garment.

Pipes and pressure vessels inside nuclear power plants give off significant amounts of waste heat. Temperatures inside a plant can reach 55°C (131°F)—not a comfortable climate for maintenance workers who are swathed in radiation protection gear and tussling with repairs. Workers cannot remove extra clothing to cool off, but they can pull on extra clothing to keep cool.

Cooling garments are used at nuclear plants to keep workers cooler for longer periods of time, safeguard health, boost efficiency, and elevate morale. EPRI and contractor Pennsylvania State University recently evaluated two cooling concepts to see how they fared in laboratory and field conditions. One concept—that of using circulating liquids for cooling—was represented by two commercially available personal cooling systems. The second concept—that of using frozen water for cooling—was represented by two prototype garments recently developed by EPRI. Laboratory test results indicate that the frozen-water concept may considerably extend working time in the power plant.

Tests in laboratory and field

The frozen-water prototype garment consists of a nylon suit with scores of pockets that hold sealed 3-by-4-in plastic packets of ice. A pair of insulating coveralls is worn over the suit. Total weight of a frozen suit is 16 lb (7.26 kg). The commercial liquid-cooled models use a battery-driven pump to circulate a cool liquid over the chest and back through the capillaries of a special vest; one model has a head covering also.

The performance tests were carried out in the laboratory and in actual field conditions at three power plants: Duke Power Co.'s Oconee station (Seneca, South Carolina); Public Service Electric and Gas Co.'s Salem station (Lower Alloways Creek, New Jersey); and General Public Utilities Corp.'s Three Mile Island station (Middletown, Pennsylvania).

Under laboratory conditions of 55°C

After the ice packets have been properly positioned for the upcoming task, the inner garment goes over the worker's ordinary underwear. A lightweight, insulating outer garment is then pulled over the first garment.

(131°F), representative of the severe temperatures that can be expected in a power plant, stay-time without cooling was 52 minutes. With the liquid-cooled systems, it was 65 minutes; with the two frozen-water garments (one waist-length and the other knee-length), it was 103 and 178 minutes, respectively. The field tests, which involved only the frozen-water garments, were conducted in temperatures of 18–43°C (65–110°F) and yielded similar results: the frozen-water garments more than doubled stay-time, compared with the test control. (These stay-times are not actual work stay-times; they represent test conditions only.)

Free to move

Besides extending stay-time, the frozen-water garment also allows worker mobility, according to John O'Brien, who manages the project in the Engineering and Operations Department, Nuclear Power Division. Power plants are often cramped places to work, but the ice packets tucked into the inner pockets of the frozen-water garment can be moved to accommodate the requirements of each job. For instance, if the worker must lie on one side, the packets on that side can be relocated to the other areas. The number of packets can also be adjusted to cooling needs, according to a simple formula.

The frozen-water garment is also compatible with other gear that plant maintenance workers must wear. Usually a radiation protection suit must be placed over cooling garments. Sometimes a face mask and air canister are added for repair situations requiring respiratory protection. The frozen-water garment was found to work well with other protective equipment.

Since the ice packets are easily removed, the frozen-water garment is also easy to clean or decontaminate. To prepare a suit for reuse, the packets are refrozen and inserted into the cleaned garment; the unfrozen packets may also be slipped into the garment, and the entire garment hung in a freezer.

The outer garment's insulating capabilities keep the ice from melting too quickly in the plant environment, which can reach temperatures of 55°C (131°F) from the heat given off by hot pipes and pressure vessels.

Simplicity is another benefit of the frozen-water garment. Unlike liquid cooling systems, whose batteries and motors require maintenance, the frozen-water garment has no moving parts. It should also be attractively priced: O'Brien estimates that the new garment would cost $300–$400 if mass-produced. Price is an especially important consideration should a utility require many suits (perhaps 50–60) to outfit workers during a major outage.

Test results and specifications for the frozen-water garment are detailed in an EPRI report. One firm, Ergocon, Inc., recently manufactured several of the garments, and they are now in service at a number of nuclear plants. In fact, about 30 of the garments are being used in the ongoing cleanup at TMI's Unit 2, according to O'Brien.

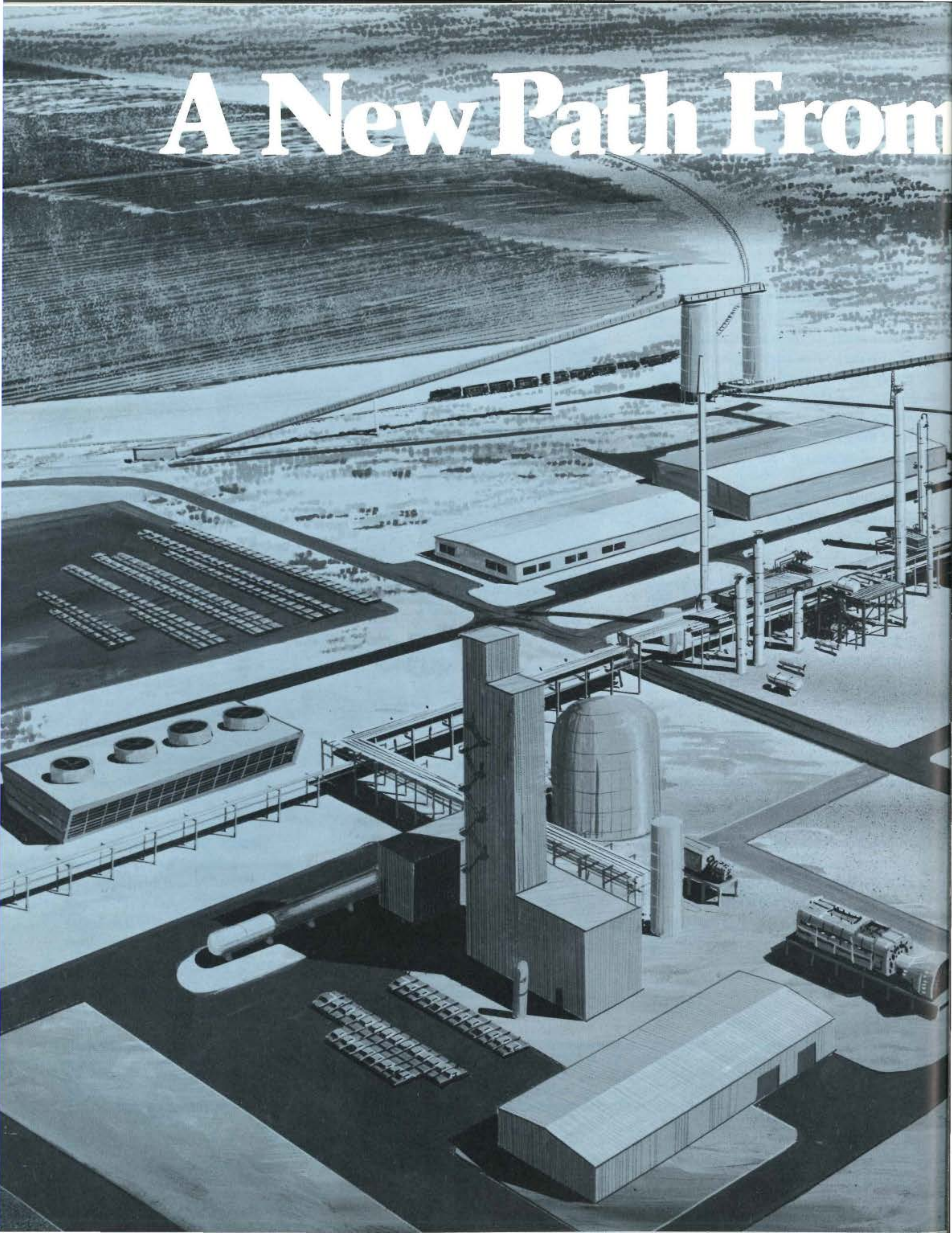
Cooling garments are only part of the solution to working in the high-temperature areas of a power plant. One of O'Brien's next projects is a guide that utilities can consult to protect the health and safety of maintenance workers. The guide will include a system for screening workers who might be at high risk in certain maintenance situations. Scheduling of work and rest cycles will be explored; so will such personal warning devices as skin-temperature monitors. Educational seminars held by utilities for their maintenance personnel to discuss such subjects as warning signals of heat exposure or how to pace work will be evaluated. The guide will be completed within the next two years.

Heat, humidity, and close quarters can all conspire to make maintenance work in power plants a tough task. But the right research can help people work around those arduous situations.

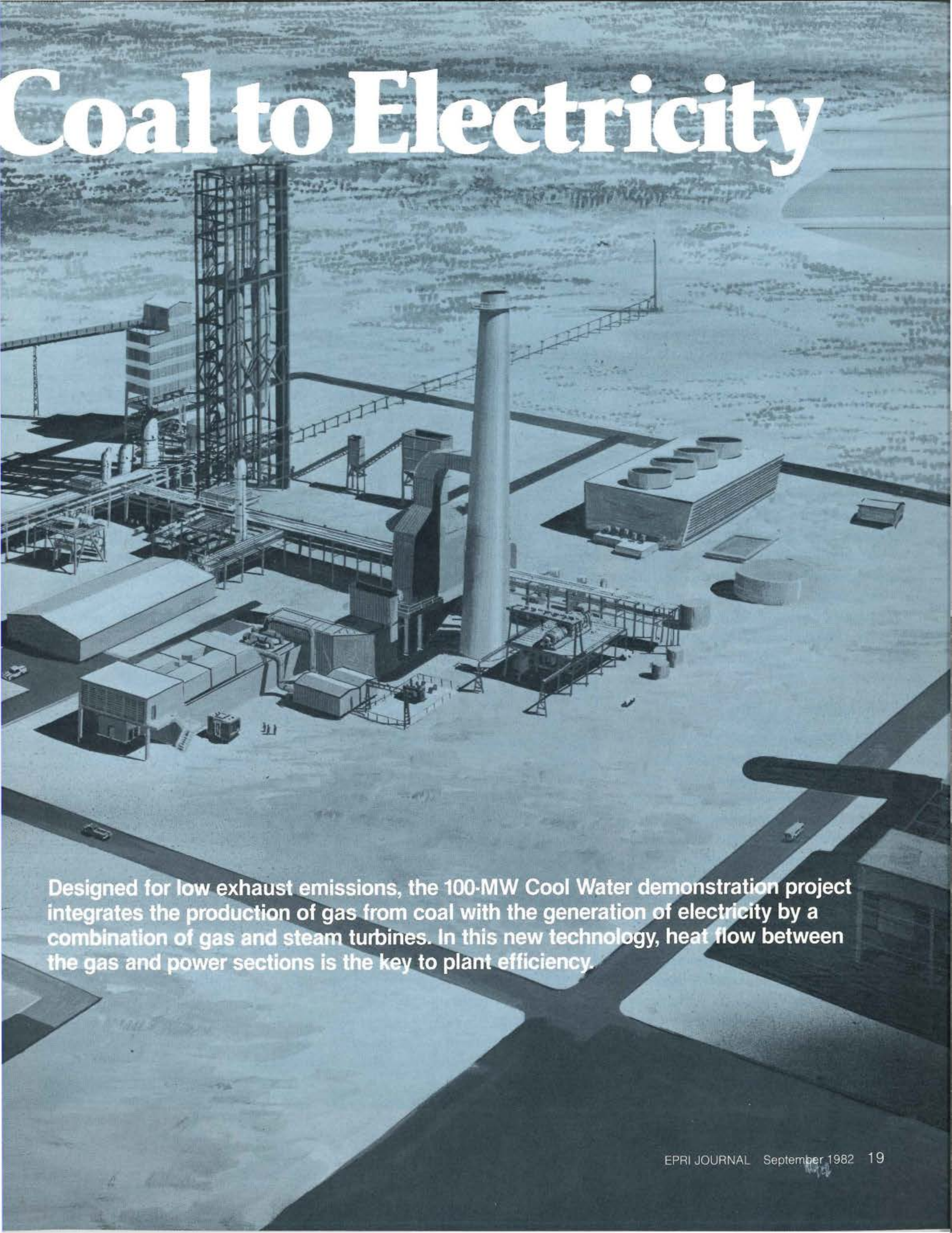
This article was written by Nadine Lihach. Technical background information was provided by John O'Brien, Nuclear Power Division.

The worker can still add two radiation-protection suits, as well as protective hood, gloves, and shoes, without impairing his mobility. Prepared to face both heat and radiation, the worker moves on to his assignment.

A New Path From



Coal to Electricity



Designed for low exhaust emissions, the 100-MW Cool Water demonstration project integrates the production of gas from coal with the generation of electricity by a combination of gas and steam turbines. In this new technology, heat flow between the gas and power sections is the key to plant efficiency.

Construction began late last year on a new kind of power plant in the California desert about 100 air miles northeast of Los Angeles. By the summer of 1984, if all goes well, rail shipments of coal will begin to arrive from a Utah mine some 500 miles away, and electricity will begin to flow into the Southern California Edison Co. (SCE) system.

Coal? For electric power in California? It seems incongruous for the state that is number four nationwide in oil production. Besides, California is where industry, urbanization, and the automobile combined to make famous the atmospheric blanket called smog. As a result, California's air quality regulations include the tightest limit in the United States on nitrogen oxide emissions from power plants.

Actually, the new plant at SCE's Cool Water station near Barstow will not simply burn coal to make steam in the usual way. It will convert coal to hot synthesis gas (syngas), which in turn will fuel a combustion turbine and also yield heat for a steam turbine. With a coal input of 1000 t/d, the two turbines will together generate a net power output of about 100 MW.

Why the plant is important

Cool Water is a commercial-scale demonstration project for integrated gasification–combined-cycle (IGCC) power technology. Integration means that the coal gasification and electricity generation processes are simultaneous and synchronized; there is no buffer of stored fuel between them. Even more important, the processes actually interact, notably by their exchange of heat. These features are key to the efficiency and economy of IGCC plants, designed to compete mainly (but not solely) with coal-fired steam plants.

The California site was not a prerequisite for this demonstration, but it dramatizes another IGCC feature. Exhaust emissions of particulate matter, sulfur dioxide, and nitrogen oxides are expected to be well below federal requirements for new power plants, thus meeting the still tighter limits required by California law. Because gas cleanup comes before combustion rather than after, the gas treatment volume will be a small percentage of that in a coal-fired plant and treatment should be easier, using processes that are already in commercial use. For these reasons, the incremental cost of meeting even tighter emission limits is projected to be less than for conventional coal-fired plants that use flue gas scrubbers.

Economy and environmental compliance are the top criteria for any bulk power technology. But circumstances facing the electric utility industry today introduce others, and IGCC technology shows promise for satisfying them all. For example, its use of coal, a plentiful U.S. resource, avoids the price and supply uncertainties of oil, much of which comes from abroad.

Choice in plant size and manner of operation is a key point. The U.S. economic recession, energy conservation, rising energy costs, and slowed electricity growth are circumstances that feed one another and discourage the construction of power plants. Big plants, which offer economies of scale in steady-state operation, are particularly difficult to bring on-line because of long lead times and inflation.

However, estimates suggest that IGCC plants could be built cost-effectively in modular increments of about 250 MW, easing financial requirements and allowing new utility capacity to more closely match system load growth. Lead times are expected to be short—as short as five years for building multiple-module plants.

Another feature of the Cool Water design is its provision for plant operation throughout a range of daily cycling and at reduced load, as well as at continuous full load. IGCC units should therefore be flexible, useful in baseload or intermediate service.

These IGCC features and their stage of development today underlie the cooperative decisions that have put Cool Water under construction. Cool Water is the all-important demonstration step that first uses equipment of commercial scale and generates electricity in an authentic utility system context. Mathematical simulation models of the Cool Water plant and its subsystems all say that integration can readily be accomplished and controlled. But confirmation must come from the actual experience.

During the six and a half years of demonstration now planned, Cool Water will be operated to test steady-state performance at rated and reduced loads, load following and transient response, and controllability on a variety of eastern and western coals. Coal-to-busbar efficiency and operating and maintenance costs will be determined. Detailed data on equipment reliability and plant availability will be obtained. Environmental performance will be rated.

Data on how Cool Water's performance measures up to projections will provide planning guidelines for the utilities, process developers, architect-engineers, and manufacturers who carry IGCC power generation into commercial practice. Training materials, as well as thorough operation and maintenance procedures, are also among the documentation planned to come from the project.

How process integration works

Coordinating the uses and control of heat available at the gasifier and combustion turbine outlets is a major IGCC technology issue. How this heat is handled provides the clearest example of process integration. It reveals how and why Cool Water is more than a simple series of process units and machinery that have been linked together.

In contrast to IGCC, essentially all the heat in a conventional steam plant follows a single path as feedwater is evaporated, superheated, and expanded through the turbines. Steam formation, especially in a so-called once-through boiler, responds to fuel and combustion control actions when the turbine throttle is opened or closed.

In an ordinary combined-cycle plant too, heat flow is mostly on one path as burned fuel gases expand through a combustion turbine and are still hot enough to evaporate and superheat steam for a steam turbine. Again, fuel flow and consequent steam production respond straightforwardly to electricity demand changes.

But at Cool Water, the heat flow path forks at a syngas cooler. The raw gas from an entrained, pressurized gasifier is at a temperature of 2300°F (1260°C) or higher, and it must be cooled to about 100°F (38°C) before it can be treated to remove sulfur. Therefore, although the gas itself (still with its chemical heat energy) goes on to fuel the combustion turbine, its sensible heat energy (physical temperature) is transferred to feedwater at the syngas cooler. Steam thus produced is piped to the combined-cycle unit's heat recovery steam generator. The heat paths rejoin there, as exhaust heat from the combustion turbine is used to produce additional steam and superheat the entire supply before it flows to the steam turbine.

The gasifier output thus affects both turbine cycles simultaneously, not one after the other. Conversely, generator load changes are reflected in altered conditions at the turbines and upstream, through two complex paths of heat exchange, all the way to the gasifier. Changing the gasifier output generally requires that coal and oxygen feed rates into the gasifier be adjusted.

Further, each process segment and mechanism has its own momentum, its own ability to respond to the changed conditions initiated or reflected from upstream or downstream. Differential response rates mean that time lags are introduced, changes may be amplified, and process variables may overshoot and oscillate before settling down at new levels. Provision must be made to accommodate these effects and at the same time

THE CLEANEST COMBUSTION EMISSIONS

Sharpest comparison of IGCC with other utility options for electricity generation has to do with combustion emissions. The main target of comparison is the baseload steam plant fired with pulverized coal and equipped with flue gas scrubbers. Most telling is the projection that emission limits more stringent than those in effect today could probably be met more cheaply with IGCC technology, largely because of one unique feature.

Sulfur, nitrogen compounds, and particulates are removed from the gas in a pressurized system before combustion occurs, even before combustion air is added. For this reason, there is a lower volume of gas to be treated—by about 99%—than in a postcombustion scrubber.

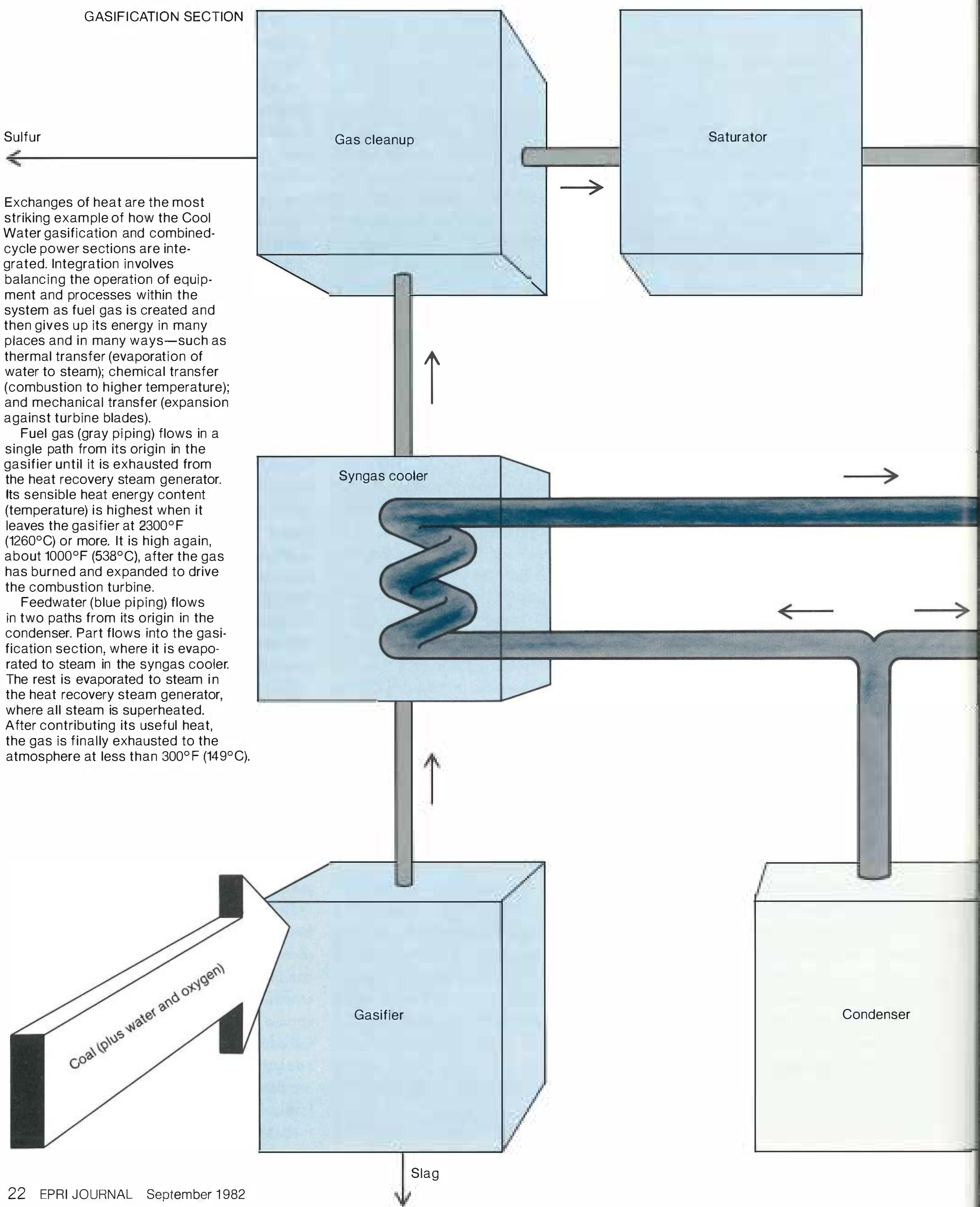
The sulfur in the coal, converted almost entirely to hydrogen sulfide in the Texaco gasifier, could be removed by any of several established commercial processes. The Selexol process at Cool Water will remove 97% of the sulfur from the gas produced when coals with a sulfur content up to 3.5% are used. Other industries using syngas even now require and readily achieve greater than 99% sulfur removal with these processes.

Some of the nitrogen in the coal shows up as ammonia in the syngas and can be almost totally removed by a straightforward aqueous scrubber before the cooled gas enters the Selexol unit. Combustion air is another nitrogen source. Nitrogen oxide (NO_x) formation in the turbine combustor is suppressed by adding moisture to the clean syngas to hold down the flame temperature. Because of the extraordinarily low California limit on NO_x emissions, the Cool Water plant has two provisions for doing this: a saturating unit before the final syngas heater and steam injection into the syngas combustors.

Particulate removal is accomplished in the same aqueous scrubbing step, which also acts to remove some heat from the raw syngas. Linked with the scrubber are settling facilities for recovering and recycling all particulate matter (which includes some coal fines).

Quenched slag from the bottom of the gasifier and elemental sulfur from the sulfur recovery unit are the final solid IGCC wastes. Tests of slag from pilot runs, using EPA procedures, indicate that it is inert and not hazardous. At Cool Water, it will be stored in a small lined pond until it is categorized under evolving California standards and its possible by-product use and value are determined. Elemental sulfur, of course, is a commercial commodity, and customers for this material will be sought. To a significant degree, IGCC technology thus is advantageous in waste volume, character, and area requirements for waste disposal.

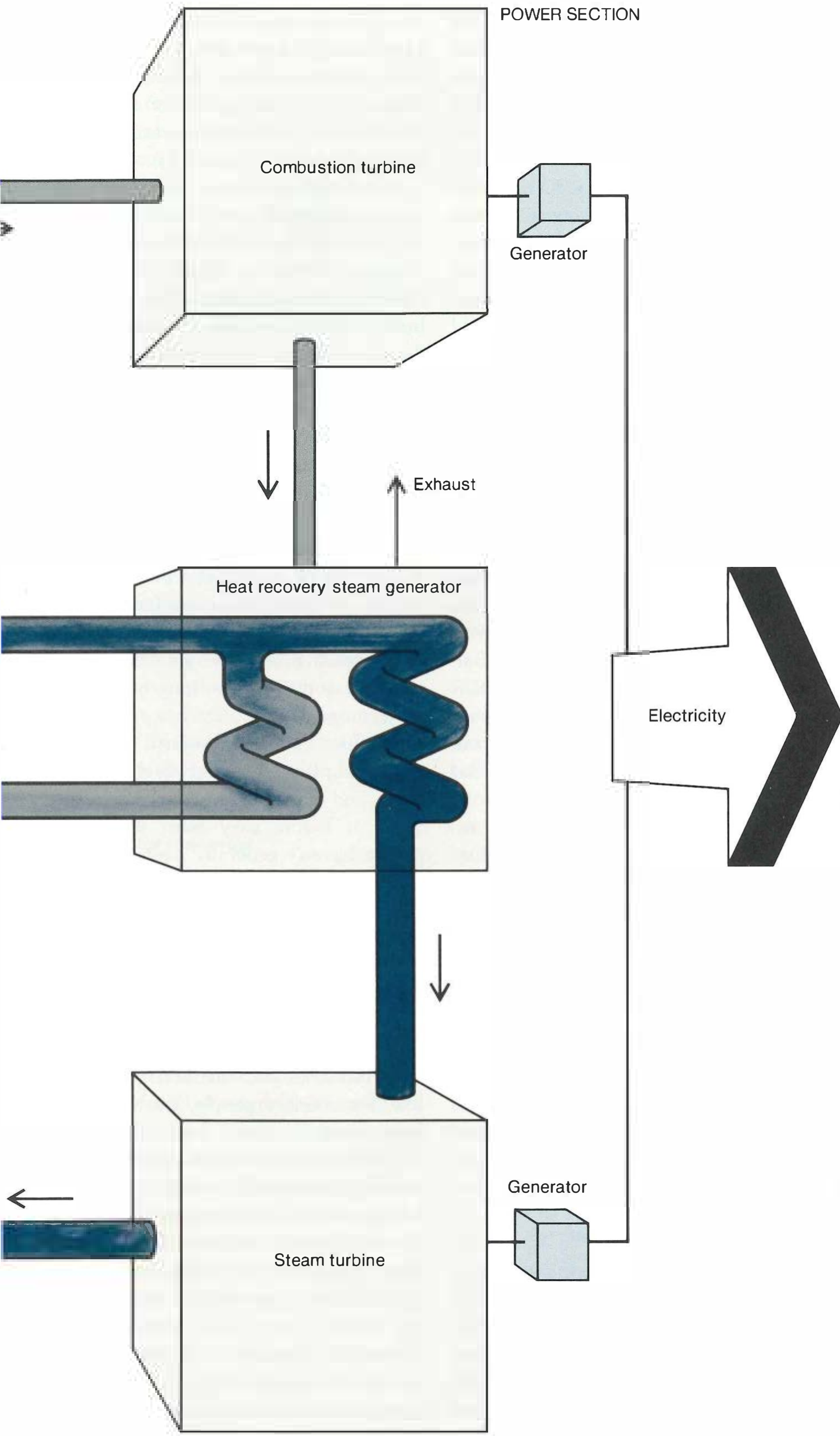
Water use is another point. Compared with a pulverized-coal plant of like generating capacity, IGCC water consumption is expected to be about 65%. Effluent from Cool Water will go to a lined evaporation pond. Most of this water will be from cooling system blowdown, very little from the IGCC process. □



Exchanges of heat are the most striking example of how the Cool Water gasification and combined-cycle power sections are integrated. Integration involves balancing the operation of equipment and processes within the system as fuel gas is created and then gives up its energy in many places and in many ways—such as thermal transfer (evaporation of water to steam); chemical transfer (combustion to higher temperature); and mechanical transfer (expansion against turbine blades).

Fuel gas (gray piping) flows in a single path from its origin in the gasifier until it is exhausted from the heat recovery steam generator. Its sensible heat energy content (temperature) is highest when it leaves the gasifier at 2300°F (1260°C) or more. It is high again, about 1000°F (538°C), after the gas has burned and expanded to drive the combustion turbine.

Feedwater (blue piping) flows in two paths from its origin in the condenser. Part flows into the gasification section, where it is evaporated to steam in the syngas cooler. The rest is evaporated to steam in the heat recovery steam generator, where all steam is superheated. After contributing its useful heat, the gas is finally exhausted to the atmosphere at less than 300°F (149°C).



move smoothly and quickly to the required operating level.

Normal fluctuations in coal feedstock cause process variables to interact, even when load remains constant. Changed ash content and chemical composition are reflected in gasifier temperature and in the total energy content of the syngas, which will carry different amounts and proportions of chemical and sensible heat. These in turn alter the relative steam loads at the syngas cooler and heat recovery steam generator, requiring careful control of steam turbine inlet conditions to serve electrical load and (at the same time) maintain temperature in the final stages of the turbine. The latter is important; for example, falling temperature results in premature condensation, subjecting turbine blades to severe erosion and corrosion by the water droplets and the trace chemicals they contain.

Combustion turbine controls also play a part in controlling steam turbine conditions, whether the impetus is feedstock change or load change. Air inflow to the combustion turbine compressor affects the exhaust gas temperature and thereby influences heat transfer to steam in the heat recovery steam generator.

Adjusting compressor air flow helps control plant operation down to about 85% of rated load. For the flexibility to operate at lower loads, Cool Water's design also allows steam system pressure to vary so that turbine temperature and moisture requirements continue to be met, despite reduced steam flow. This must be accomplished without triggering adverse effects in the syngas cooler and heat recovery steam generator. Examples would be formation of steam in the final feedwater heater (economizer) tubes or the excessive cooling of syngas, leading to water vapor condensation and consequent corrosion.

Entrained gasifier operation

Speed and precision of gasifier response are obviously important elements in successful plant integration. The Texaco, Inc., gasification process is inherently responsive. Reviewing this and other characteristics of the process shows why it was chosen for Cool Water.

The gasifier is a simple reactor vessel, with no internal moving parts, into which are injected streams of a coal-water slurry and oxygen. The slurry medium is easy to transport and meter. Also, the water acts as a moderator for temperature control in the gasifier.

Small coal particle size, entrained flow, and special burner design ensure thorough, continuous contact of the reactants, hence, short reaction time and a close coupling of the exiting gas flow rate with the entering slurry feed rate. This is fast response.

Because the entrained gasifier requires ground coal, it easily tolerates the natural fines in a coal supply, which tend to agglomerate and plug other types of gasifiers where the coal lies in a bed. In fact, because coal particles are separated from one another in the gas stream, even sticky or caking coals can be used. Some 40 coals have been run through the Texaco process. This is feedstock flexibility.

High temperature and pressure also promote reaction speed, which means high energy throughput. High temperature has its own advantage, precluding the formation of tars and oils that necessitate additional treatment steps in the lower-temperature gasification processes. High pressure also means a smaller gas volume in the subsequent cleanup step, and it does away with the need for a fuel gas compressor ahead of the combustion turbine.

These advantages have been well documented in Texaco's 15-t/d process development unit at Montebello, California, and in a 165-t/d demonstration unit jointly owned by Ruhrkohle and Ruhrchemie at Oberhausen, West Germany. EPRI has used both gasifiers for extensive testing over a range of operating conditions and for performance evaluations during the past few years of R&D.

The Montebello and Oberhausen facilities, in turn, are built on 30 years' Texaco commercial experience in using essentially the same approach to produce syngas from heavy oil, natural gas, and other petroleum feedstocks. Two other coal-based plants comparable in size to Oberhausen have been built in the United States, one to produce synthesis gas for ammonia manufacture (TVA), the other (air-fed) to produce fuel gas for electricity generation (Dow Chemical Co.). Also, a Texaco plant about the size of the Cool Water demonstration is being built to produce chemical process feedstocks (Tennessee Eastman Co.).

Against its many advantages, the Texaco gasification process presents some areas of concern. One is the corrosion and erosion effects of the high-temperature slagging environment in the gasifier and the syngas cooler; another is the potential for fouling the cooler surface. Both conditions require special attention to materials selection and configurations that show promise of acceptable component lifetimes. Coal gasification tests at Oberhausen—3500 t of Utah coal and 4400 t of Illinois No. 6—indicated that the gasifier refractories should have service lives of at least one year, putting them in the range of commercial acceptability.

Syngas cooler tube spacing can be increased to deal with fouling, but wider spacing, like fouling, cuts heat transfer efficiency. This increases the total surface area needed for heat exchange and adds to the overall unit size and cost. The syngas cooler units for Cool Water are much larger than those at Oberhausen. They are the largest that can be shop-fabricated for shipment, and their cost far exceeds that of the gasifier. The design and performance of these units are therefore critical to the successful operation of Cool Water.

Drawing industries together

The Cool Water engineering design is more than half complete, and all major equipment has been ordered. The orderly progress of Cool Water engineering, procurement, and construction today suggests a certainty that has not always been there. Technical confidence, yes, because seven years of background R&D have clearly led to both the IGCC concept and the specific process options chosen. But the integration of organizations was an early source of uncertainty that dissipated only gradually.

"Power industry unfamiliarity with the process aspects of gasification was a special issue that had to be dealt with," says Thomas O'Shea of EPRI's Advanced Power Systems Division. "But that cut both ways," he adds, "because the developers of the gasification and syngas cleanup processes weren't familiar with electric utility needs and practices, either."

O'Shea has served as EPRI's Cool Water project manager for four years, and he speaks candidly of the attitudes and relationships that are evolving.

"Cool Water isn't just a process synthesis. It's a first-time cross-fertilization and educational effort between utility and chemical process people. This is part of the reason it took so long to put the project together.

"Utilities aren't accustomed to operating fuel plants. They buy fuel over the fence and don't have to be concerned about it before they burn it. Utility people haven't generally been process-oriented, either. But this doesn't mean they can't be, because there's nothing simple about running a steam plant.

"Now, IGCC is new," O'Shea concludes, "and there are barriers to be knocked down. Cool Water is an opportunity for utility people to understand what refineries and chemical plants are like. For refinery people, it's the other way around."

The $300 million Cool Water project formally began with a 1979 agreement between SCE and Texaco, encouraged by the R&D results and feasibility studies done by and for EPRI. The Institute itself became a participant in 1980, as did Bechtel Power Corp. and General Electric Co. They were followed in 1982 by the Japan Cool Water Program Partnership, a group of four organizations headed by Tokyo Electric Power Co., Inc.

The project obligations of these organizations (in funds, loan guarantees, and facilities) range from $30 million to $111 million. Each organization is represented on the Cool Water Board of Control and Management Committee. New York's Empire State Electric Energy Research Corp. (Eseerco) is also a contributor.

Major technical responsibilities are held by Texaco, of course, for the gasification process and by General Electric for the combined-cycle equipment and the integrated control system for the plant. SCE is the host utility; in addition to its financial commitment, its contribution includes the Cool Water site (where four power units already generate 600 MW), the plant water supply, and the use of various other facilities.

Bechtel is engineer-constructor for the project. Combustion Engineering, Inc., is supplying the gasifier vessel and syngas cooler units. Airco, Inc., is building an air separation plant adjacent to the Cool Water site and will deliver oxygen "over the fence" to the IGCC plant. Ford, Bacon & Davis is designing the sulfur recovery system.

Answers for tomorrow

As sponsor of a great deal of the R&D that led up to Cool Water, EPRI continues to provide much technical coordination and leadership, as well as to seek further sponsors to share the cost of the demonstration. Much EPRI-funded work bears directly on Cool Water and on the mitigation of risks associated with it. Pilot runs at Montebello and Oberhausen are examples. Also, tests of rapid load change were conducted at a 1000-t/d commercial oxygen plant in Texas. Computer simulations were used to model various IGCC control modes (involving Texaco and other gasifiers); and work continues in refining models of the gasification process itself.

The Cool Water project organization, with input from EPRI in several instances, has performed studies leading to the final decisions on oxygen storage, sulfur removal and sulfur conversion processes, coal-grinding equipment, fundamental configuration of the gasifier and its immediate auxiliaries, and equipment spares for reliability.

The most provocative analyses to come from the Cool Water background R&D are the projections of capital cost and performance factors for a commercial IGCC plant. In mid-1980 dollars, one such design is estimated to cost $1200/kW. This figure reflects 1000-MW capacity (10 times the size of Cool Water) and a 35.5% thermal efficiency (9618 Btu/kWh heat rate).

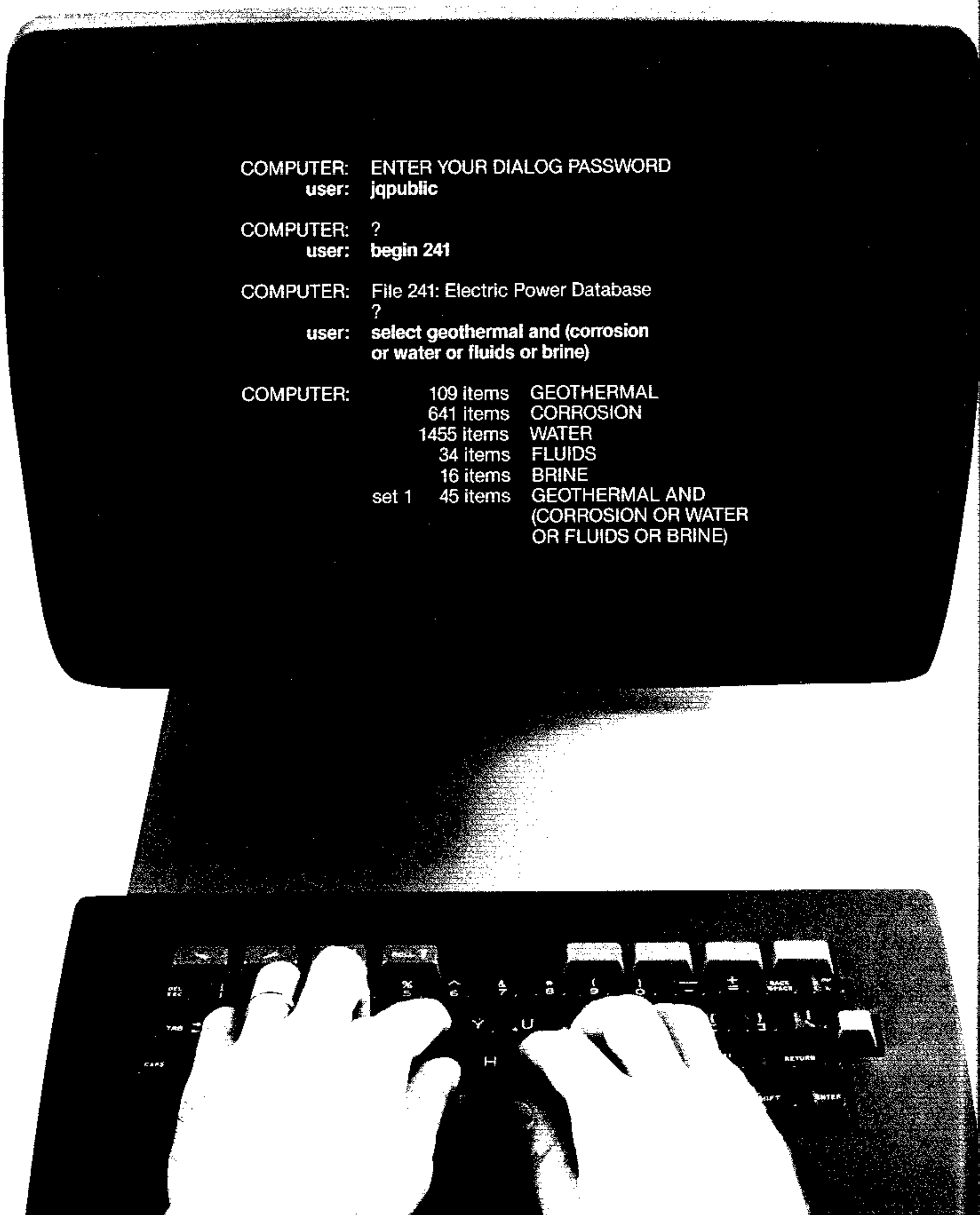
If the 100-MW Cool Water capital cost is adjusted to the same mid-1980-dollar basis, it is $2290/kW. And if the Cool Water thermal efficiency, calculated at about 31%, is adjusted upward to 35.5% (largely by assuming a steam reheat cycle as in a larger plant), its equivalent cost drops to $2000/kW.

The difference between $2000 and $1200 is considered reasonable and encouraging for a first-of-a-kind demonstration plant. According to standard calculations used in industry, it represents a scale factor of 0.8. That is about the figure to be expected for a ten-fold capacity increase involving a combination of larger individual units (sulfur removal plant and steam turbine) with parallel trains of smaller units (gasifiers, syngas coolers, and combustion turbines).

Three utilities are already following the progress of Cool Water and these analyses very closely and are considering Texaco gasification and the IGCC technology for future needs: the 500-MW Sears Island plant for Central Maine Power Co., a cogeneration plant of still-undecided capacity for Arkansas Power & Light Co., and the 1500-MW Ivanpah plant for SCE.

If design and construction schedules continue to be met, Cool Water will be on-line in 1984, producing electricity and providing data only 12 years after EPRI itself began operation. That interval reflects an early and important change in EPRI's objectives for advanced fossil fuel power research. What began as a search for the best coal gasification process gave way to a search for the best integrated power technology. Taking full advantage of its own findings, while acknowledging the preeminence of others in gasification and combined-cycle systems, in fairly short order EPRI has zeroed in on a promising new candidate to generate clean power from coal.

This article was written by Ralph Whitaker. Technical background information was provided by Thomas O'Shea, Advanced Power Systems Division.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user: begin 241
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user: select geothermal and (corrosion or water or fluids or brine)
COMPUTER: 109 items GEOTHERMAL
641 items CORROSION
1455 items WATER
34 items FLUIDS
16 items BRINE
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Information at Hand

Evolution in computer and telecommunications technology has spurred the development of worldwide commercial information networks that link users to a growing number of data bases at the push of a button. Access to the Electric Power Database, including information on EPRI-sponsored research, is now available on-line through the DIALOG system.

The search for information on corrosion in California geothermal energy research begins with identifying appropriate key words and the number of information items available on each. The computer can then be asked to combine several categories or sort out items that have several key words in common. When the field of information has been narrowed sufficiently, citations can be printed out in a form that gives basic information and an abstract of the research. The example on the screen shows the logic of such a search, although the actual user-computer interaction would be somewhat more abbreviated.

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? select cs=california energy commission
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? combine 1 and 2
        3     4   1 AND 2
? type 3/5/1-4
3/5/1
805900
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  INVESTIGATORS: California Energy Commission
  CONTRACT/GRANT NO.: CEC
  800701  TO 820630    FY: 1981    FUNDS: $150,000    DATE ENTERED:
  FUTURE YR. FUNDS: $150,000    TOTAL PROJECT FUNDS: $300,000
  FISCAL YEAR FUNDING STATUS: YES
  FUNDING DISCLOSURE: YES
  IN-HOUSE: NO
  CONTACT: Morse, David
           Mgr., System Assessment
           9169206426
  The purposes are: (a) to identify, develop, and test various energy
strategies for the state; (b) to integrate the analyses and products of
other Planning Elements; (c) to evaluate specific projects or other
portions of the energy system in the state; and (d) to assess the utility
resource plans and reasonable alternative methods to meet forecasted
electricity demands. Activities include: (1) developing a more
probabilistic method to determine the state's hydroelectric power capacity;
(2) developing a model to examine the workings of several utilities
jointly; (3) integrating analyses of alternate energy scenarios; and (4)
characterization of cooling tower emissions, particularly of those towers
for geothermal plants and power plants using waste water.
  DESCRIPTORS: *Models; *Energy demand; *Energy supply; *Cooling towers;
*Hydroelectric power plants; *Power systems analysis
  SUBJECT CATEGORY: 10.01E Integrated Energy-Economic Models
  FERC CATEGORY: A(6)

3/5/2
805600
  Geothermal Program
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  FUNDING DISCLOSURE: YES
  IN-HOUSE: NO
  CONTACT: Brown, Susan
           Geothermal Program Specialist
           9169242499
  The purpose is to accelerate the development of geothermal steam, hot
water, and direct heat resources in California. Anticipated results
include: (1) assessments of the state's geothermal energy potential and
estimates of those resources expected to be deployed; (2) resource
verification and planning studies for locations in Modoc, Los Angeles,
Inyo, and Mono counties; (3) feasibility studies, demonstrations, market
studies, and implementation plans for various geothermal direct use
applications; and (4) grants to local governments for geothermal planning
and development activities.
  DESCRIPTORS: *Geothermal power generation
  SUBJECT CATEGORY: 05.05 Geothermal Power
  FERC CATEGORY: A(1)e

3/5/3
507100
  Imperial Valley
  INVESTIGATORS: California Energy Commission
  CONTRACT/GRANT NO.: CEC4-B-5202
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Manila, August 1982: A civil engineer sits down at a small computer terminal with a telephone hookup and dials a local number. What he wants is information that will help him in cost-effective siting of an electric power transmission line through a technically challenging stretch of the Philippine jungle. The number he calls will connect him not with the local library, which lacks the information he needs, but with the resources of a giant computer located in the United States.

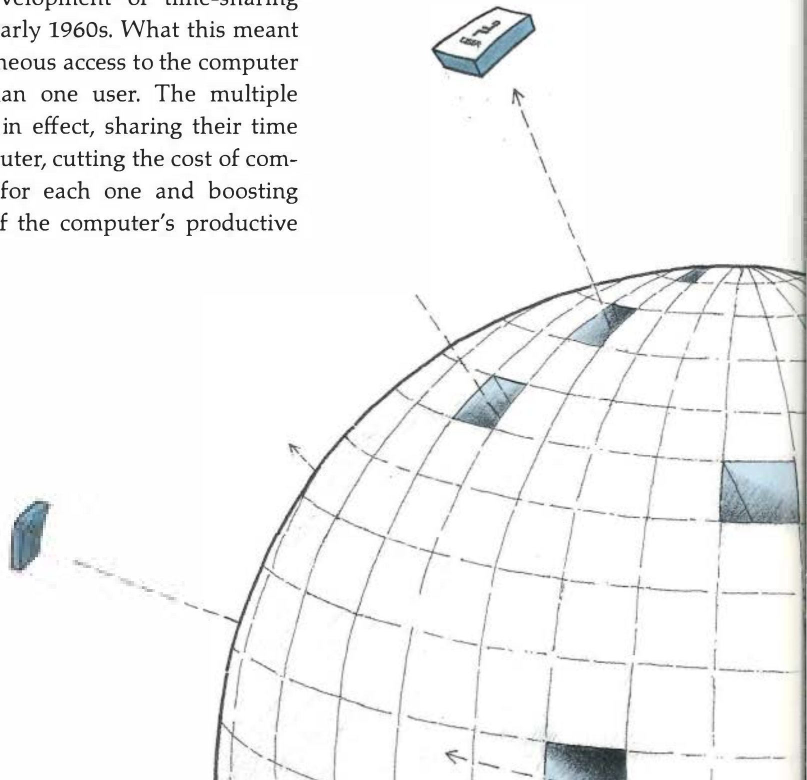
Through this trans-Pacific circuit the engineer can scan, select, and print out summaries of EPRI research at his own terminal. The method is fast and relatively cheap, and it ensures access to material that is too new to be widely available, even in U.S. libraries.

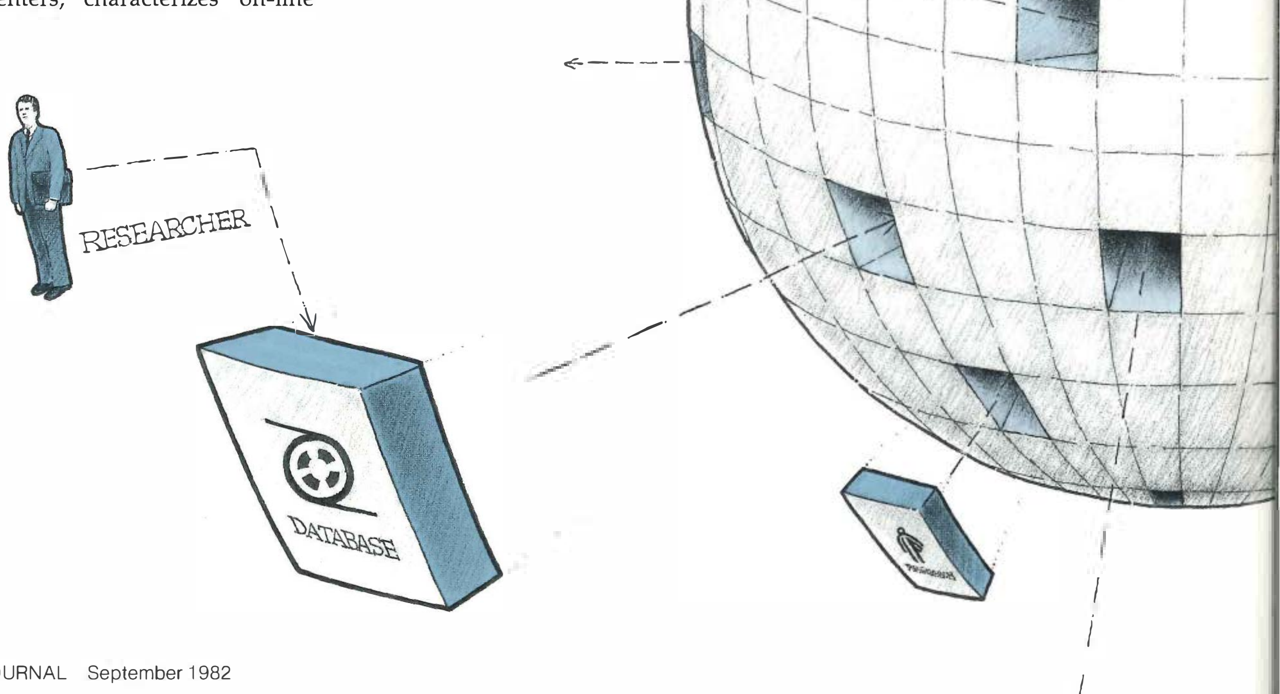
Such a scenario first became possible this past summer, when EPRI joined the growing number of research institutions that are becoming part of a worldwide commercial information network. How did this trend toward computerized information-sharing begin, and where does it seem to be going?

On-line evolution

Behind today's information boom lies the development of on-line data retrieval. Donald Black, manager of EPRI's Information Centers, characterizes on-line retrieval by the interaction that occurs between computer and user. The on-line user engages in an active dialogue with the computer, making requests and receiving answers until he has the information he wants. "The on-line interaction," says Black, "allows the user to refine his questioning strategy as he goes."

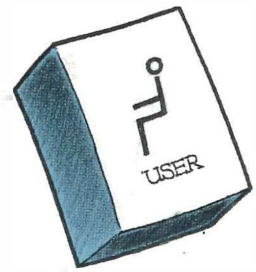
The seed of today's on-line network was the development of time-sharing during the early 1960s. What this meant was simultaneous access to the computer by more than one user. The multiple users were, in effect, sharing their time on the computer, cutting the cost of computer time for each one and boosting utilization of the computer's productive capacity.

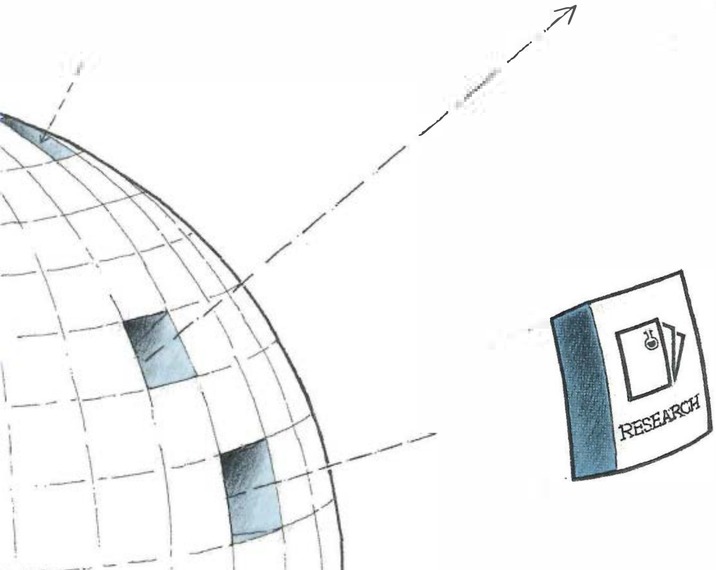


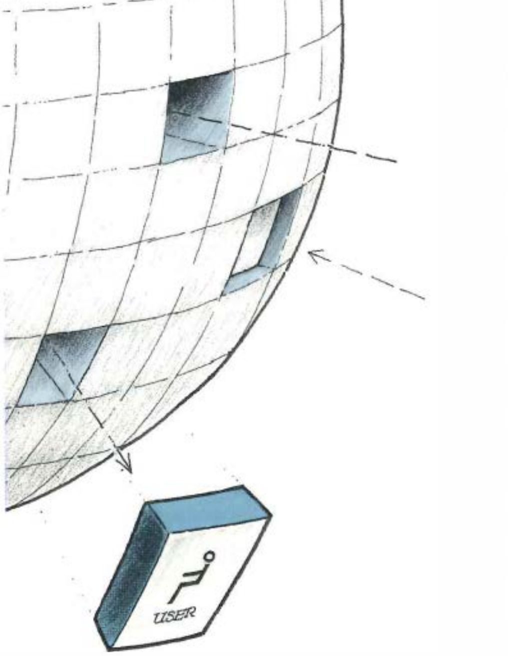


Into the Global Pool

Linkage to the research work of others is increasingly available through global information pools that can be tapped by computer information networks. Abstracted information fed into ever-larger data sets can be retrieved by any user through on-line terminals. For example, vital information on 3600 EPRI-sponsored research projects, part of the Electric Power Database, has recently been fed into the commercial system called DIALOG. This large pool houses some 160 data bases containing over 55 million records that range from engineering through the physical and biological sciences to humanities, business, and environment. All records are immediately available to any of the 15,000 users worldwide.







To handle their multiple requests in a sufficiently rapid sequence to create the illusion of simultaneous processing, the computer's central unit—its brain—had to grow. In the early machines, a few thousand units of memory were considered a liberal endowment; today, even the smallest microcomputers have more than that. So a smarter and speedier central processing unit was the first precondition for the development of time-sharing.

A new storage medium was the next step. Storing data on tapes slowed the search process because tapes had to be read sequentially, from beginning to end. Magnetic disk storage offered freedom from this constraint, providing random access to any file designated without the need to go through other files. Disk storage also gave greater capacity at progressively lower costs over time.

But the market for computer services was still limited by geography. If, for example, a company in Omaha could reach potential customers for its computerized accounting services package in Seattle and Cleveland, the increased volume would mean lower costs per user. This realization provided the impetus to create a communications network that would bring the customer to the computer, regardless of the real distance between the two.

To avoid the expense of daytime long-distance rates, computer service bureaus started to lease circuits by the month. What they developed were value-added networks that could do far more than just pass electric signals back and forth between the host computer and customer terminals. One pioneering concern discovered a way to make a single voice-grade circuit service some 64 customer terminals, spreading the cost of the circuit over 64 users. In addition to this cost breakthrough, the special circuits could provide automatic routing to the proper host computer, manage diverse types of computers and terminals to make them compatible, and provide instant backup in case a line went down.

Three developments were critical, then, in making large-scale computer networks possible: enhanced speed and memory in the central processing unit, random-access disk storage, and low-cost telecommunications capability. Once the necessary conditions were met, time-sharing took off.

Time-sharing and *on-line* became roughly interchangeable terms. The time-sharing concept, which came first, emphasized simultaneous access to the computer by many users. On-line data processing stressed the interactive link between the computer and each one of these users. But, as Black points out, "Time-sharing isn't meaningful as a concept unless you are on-line." Today's multiple users of a giant host computer are far more likely to be scattered around the globe than gathered in one spot, so the distinction has meant little in practice.

Data base development

"There is a big world of on-line information out there," says Black, "and we're adding our part to it now." That contribution is the Electric Power Database (EPD) compiled at the Institute "to help meet one of our missions, which is to disseminate information to our members—and beyond them, to the scientific community and the public at large."

Building today's on-line data bases began with efforts sponsored by the U.S. government back in the late 1960s. The National Aeronautics and Space Administration (NASA) wanted to disseminate information about the space program, while the National Library of Medicine grappled with the task of indexing and abstracting the world's medical literature. Because of the difficulty of keeping printed material current with the flow of incoming data, they decided to try computer-controlled publishing for speed. This move meant that the data to be published had to be put in machine-readable form.

"Nobody thought of the possible benefits of having machine-readable data until after it was in existence," Black comments. The motivation had been simply to expedite printing. But with the simultaneous development of the technology for on-line information search, it became clear that the coded data did not have to be printed in order to be useful.

In fact, an on-line data retrieval system such as today's EPD can offer a number of advantages over traditional methods of poring through printed materials in search of information. For a start, it is faster. The latest additions to the data base are available right away. And through the multiple access points that are not available in printed literature, it is possible to zero in with maximum efficiency on the areas of greatest interest.

For example, when searching the data on geothermal power systems, it is possible to call for only those projects handled by a certain contractor, or only those focusing on dry steam resources, or only those with a certain level of funding. Alternatively, if scanning all the industry's research in the field is important, it is all available—without gaps, missing issues, or torn-out pages.

Access is not limited by geography, either. The facts are literally at the searcher's fingertips. Substituting computer communication for physical travel to libraries or to EPRI itself allows on-line users to delve into the Institute's information stores without ever leaving their homes or offices, a convenience that saves money as well as time.

A typical search might cost $10–$15. That would pay for about 10–15 minutes of on-line scanning, as well as the summaries printed and mailed out immediately thereafter. Printing the summaries on-line, at the customer's own terminal, costs more because it takes more computer time. If the printing is done off-line, even a full hour's search with several hundred printed citations would cost no more than $75–$85.

Using EPD

Originally abbreviated as EPD/RDIS in reference to the earlier Research and Development Information System that the Institute's new system incorporates, EPD embraces some 8500 records on electric power research throughout the industry, including over 4000 on EPRI-sponsored projects. These records give a wide scope of information: project title; contractor; funding for current, prior, and future years; project description for projects funded at $15,000 or more; subject headings and classifications identifying areas of concentration of the research; and any resulting publications. In total, the records contain contract information on research representing an annual industry funding level of $500 million.

EPD is updated monthly to stay on top of all the most recent developments. About half the records detail research that is still in progress. Because a new record is added as soon as an EPRI research contract is initiated, EPD users can be sure that they will know what work is being done in the field well in advance of any publications documenting the results. Furthermore, old records of completed projects are retained to ensure comprehensive, in-depth information access.

This wealth of information has been available on-line for some time through the DOE/RECON government system. But it was accessible only to government agencies, to government contractors, and by special arrangement, to EPRI member utilities. Now others have the same opportunity because DIALOG, the information service that EPRI joined this past summer, is not restricted and is available worldwide.

Further, EPD may soon be available through more commercial services, so potential users will have an even wider choice of retrieval features. And searching other data bases offered through the same services may help EPD users gain important supplementary information.

Becoming an on-line user is easy. DIALOG and most other services have no subscription fee and no monthly minimum. Like a utility, they charge basically for what is consumed. Some even give a limited amount of free on-line time to new users so they can become acquainted with the system, a process that is made far speedier and more efficient if the user takes the on-line training that is offered at nominal cost. (EPRI's technical information center staff can provide assistance to those interested in becoming on-line users.)

The value of on-line data retrieval runs in the millions of dollars every year. For example, a recent DOE study estimated that the $5.8 billion spent annually on its R&D required an additional $500 million for information processing and use but that these services pay for themselves by saving scientists and engineers $13 billion in time and equipment. No equivalent study has been done at EPRI, but Black considers it reasonable to expect similar kinds of savings from on-line use of EPD.

Expanding the resource network

Given the history and nature of on-line data retrieval, what is the outlook? What are the frontiers of the on-line network as computers enter their third decade?

The first and most obvious frontier is geographic. The on-line data network is spreading around the world, with local access points, called nodes, now available in about 30 countries; there are over 900 nodes in the United States. So far, most of the traffic has been one way. Users from Singapore to Buenos Aires have been plugging into some 350–400 host computers clustered in the United States. But modifications of this pattern are now in view.

Soon network users, including those in North America, will be able to access host computers in Europe. And eventually, anyone at any access node on the system will be able to reach any host computer in any country that the system serves. For example, Australia has computers that are not yet accessible to researchers in the United States and Canada, but the Australian data bases in such important fields as minerals exploration and zoology will be opened up to on-line researchers worldwide over the next few years. Already the more than 180 on-line information services based in North America alone offer some 1100 separate data bases, and that number will multiply when instant computer access to foreign information sources becomes a reality.

Because the United States has been and still is the world leader in computerized information retrieval, English tends to be the network's universal language. This will probably remain true, despite the diversity now being introduced by Europeans who are building data bases in German and French. Most challenging will be the translation of the extensive data bases developed in Japanese, a complicated task that may slow the eventual access of North American and European on-line users to Japan's valuable information resources.

Geographically, then, the network is spreading across the globe as it follows development. But what of the frontiers in subject matter?

Science and technology will probably remain the leading topics of international information exchange, but other fields are catching up. Economics, law, business, and management have all gone online in the past few years. And even the arts are getting their turn, so devotees of music, theater, dance, painting, and the like will be able to follow their trends online. What's more, in the United States, consumer information ranging from instant stock market quotations to recipes for homemade yogurt is already available to on-line service subscribers.

On the technology frontier, the hottest news, according to Black, is the emergence of digital video disks for data storage. Although this technology is still in the experimental stage, more and more effort is being expended to bring the digital video disk to commercial readiness. The heart of a digital system is conversion of the data to a simple binary code—based, in this case, on the presence or absence of a dark dot at each minute data station on the disk. In contrast with the sometimes fuzzy or distorted analog video disks now sold for home TVs, the digital disk is very precise, presenting data in a form that is easy for the machine to read accurately by rapid laser scanning. As Black points out, there are no halfway measures in the recording or the reading of a digital disk.

Even more important, the digital system allows the reduction of a great deal of data into a very small storage space. "There is the potential for storing the entire *Encyclopaedia Britannica* on one side of a disk this big," says Black, holding up a disk only 8 inches in diameter. Such extreme reduction, although still some years off, will make a tremendous breakthrough in terms of storage cost. The result will be larger and larger data bases available at lower and lower cost to the user. And the user will have instant access to far more comprehensive information, too, when an entire article or report rather than just a brief summary is available on-line.

Meanwhile, terminal costs are also falling. Whereas it now costs $1000–$2000 to purchase all the equipment necessary to go on-line, a keyboard terminal that links to a home TV screen will be available this year for less than $100. A modem to provide the necessary terminal-telephone interface and a printer to put the telephone transmissions on paper are also coming up in the same price range. Before long it will be possible to go online for only about $300 total—a sum roughly equivalent to the price of a small color TV set and well within reach of the average American.

So the on-line phenomenon has a social frontier as well, and one that is expanding rapidly. In Black's words, "The growing on-line network is a democratizing influence—with the proper equipment, it allows anybody, anywhere, equal access."

In the realm of science and technology, the prospect is that this broadened access will stimulate the exchange of ideas. At home, affiliation with a leading institution may become less important as a conduit for receiving information and offering work to the community. And abroad, the many scientists who will never travel to major research centers may now have greater opportunity to participate in new developments, contributing their own special perspectives to the advancement of science worldwide. ■

This article was written by Mary Wayne, science writer. Technical background information was provided by Donald Black, Technical Information Division.

Grappling With Federal Budget Uncertainties

This summer's AAAS forum on federal R&D policy emphasized redefinition of roles and priorities in light of the changing climate for federal support of R&D.

Political constants impose constraints on the whole architecture of the 1983 budget: the avoidance of economic disaster and a commitment to a higher and costlier level of national security. Together, these constants exert a forcing effect on choices that bear upon the discretionary fraction of the budget, which is where research and development live," stated William D. Carey, executive officer of the American Association for the Advancement of Science (AAAS).

The discretionary fraction of the federal budget was the center of discussion at the Seventh Annual Colloquium on R&D Policy, sponsored by AAAS and held in Washington, D.C., last June. The forum allowed participants from the scientific and engineering communities, federal policymakers, and others in industry, universities, and the general public to exchange views on current R&D policy issues. It also gave federal officials a chance to gauge scientific reaction to current policy proposals, including the reduction in federal spending on nondefense R&D. Energy R&D reductions are evidenced by the decreased budgets and personnel layoffs at DOE and the Environmental Protection Agency (EPA) and a reduction in funds for the national laboratories.

These cuts are consistent with the administration's economic policies, which emphasize initiative by the private sector in determining whether R&D projects reach commercialization. The lingering question at the forum was, how much of the R&D previously supported by government will industry assume? The debates also provided some insights into future R&D trends.

Budget Impacts on Energy R&D

The Reagan administration's budget, proposed in February, recommended an increase for R&D to \$44.4 billion in FY83, up from \$37.3 billion in FY81 and \$40.0 billion in FY82. This represents an 11% increase over FY82. According to George Keyworth, presidential science adviser and keynote speaker at the AAAS colloquium, R&D received the second largest increase of any of the FY83 budget functions. The majority of this research increase, however, is in the defense area, which is slated to grow 43% over the two-year period FY81–83 (in current dollars, or 23% in constant dollars).

As proposed, total expenditures for nondefense R&D are to remain relatively unchanged between FY82 and FY83, representing a 6% reduction in purchasing power. According to the AAAS analysis presented at the colloquium, of all the major components of R&D (defense, space, health, energy, general science, and other) energy suffers the greatest reduction in budget authority for FY83 (*Research and Development: AAAS Report VII*). Approximately \$4.3 billion was spent on energy R&D in FY81. That figure diminished to \$3.1 billion in FY82 and \$2.2 billion in FY83—reductions from the FY81 total of 29.2% and 48.0%, respectively.

Total R&D by DOE funding (including DOE's defense and general science programs) is facing a 25.3% reduction from FY81. In FY81, the budget authority amounted to \$6211.4 million; but only \$4639.8 million has been proposed for FY83. These funding decreases are forcing sharp cutbacks and program terminations in fossil, solar, environmental, and conservation R&D. There is limited growth in basic research and some funding increases in atomic energy and nuclear defense activities.

Also of concern are the substantial decreases for R&D at EPA. The FY83 budget of $218.2 million signifies a 43.4% reduction below the FY81 level of $385.4 million. With the exception of acid precipitation research and scientific assessment, funding for all EPA programs will decrease in the coming fiscal year.

Conversation was enlivened at the forum by a change of events: While the forum was in session, Congress passed a budget resolution restoring much of the funding the administration had proposed to reduce. The resolution provides an overall budget ceiling. It is now up to the various appropriations committees to reconcile each program area, a process that may take a number of months. Although some programs may be temporarily rescued from severe budget reductions, it is the administration's intent to continue to apply downward pressure in these areas in future budget years. And it is this uncertainty that surrounds the final budget outcome, making both short- and long-range energy program planning difficult.

Impacts on National Laboratories

The budget cuts in funding for federal agencies are having their effects on the institutions that perform R&D. Among these are the national laboratories, which receive funding through DOE. Historically, the national laboratories have responded to changing national priorities by diversifying their programs. At the present time, the multiprogram laboratories are suffering from budgets that are down about 20% from FY81 levels. Although the nuclear energy programs are faring well, the technology programs in geothermal, solar, conservation, energy storage, and fossil energy are experiencing severe budget reductions.

The specific contributions of the national laboratories can be difficult to determine. Albert Teich, coauthor of the AAAS R&D report and science policy studies manager at AAAS, explains, "National laboratories should not necessarily be viewed in terms of their direct contributions to the marketplace. They perform other very important functions, which provide the groundwork for future technology development. Asking the laboratories to cut back their staffs by 20–25% over a 1–2-year period could substantially damage their long-term health."


Teich

The role and future of the national laboratories are issues of much controversy. "If fundamental roles of the laboratories could be defined and agreed upon by all sectors of the scientific community, rather than being regarded as a problem, then scientists in universities, industry, and national laboratories would have a secure institutional context in which to conduct their real work of scientific research and development," adds David Shirley, director of the Lawrence Berkeley Laboratory and a speaker at the AAAS colloquium. The roles and missions of the laboratories are currently being examined by DOE's Energy Research Advisory Board and the administration's Office of Science and Technology Policy (OSTP). Their findings could have a significant impact on the future of the national laboratories, particularly in light of the federal budget reductions. And because of these reductions, the burden for continuing energy R&D has now shifted to the private sector.

Industry Response

By forcing the reprogramming and reshaping of federal R&D priorities, the administration can achieve its objective of shifting the major role in resolving the nation's energy problems to industry. Keyworth explains, "For nearly two decades we've been neglecting to replenish our means to keep pace with our aspirations. A whole generation in our society has literally grown up under generous government programs; to them, reductions in the rate of growth in federal spending must seem positively un-American. Actual cutbacks are unthinkable. Unfortunately, that has to be part of the solution to restoring health to our economy."

In his address to the colloquium, Keyworth pointed out that the government has misplaced priorities in support of demonstration and commercial technologies where no natural market exists, such as projects in fossil and solar energy. The government spent $30 billion on programs that did little to achieve U.S. energy independence, Keyworth added. "Why did they fail? Because there was no natural market for the products of those expensive technologies. It's no wonder private industry was reticent to invest large amounts of its own money to improve the technologies. . . . So in keeping with our policy for science and technology, we're pulling back now, removing government from those demonstration projects that would be well within the capability of private industry to make competitive, if a market exists."

The administration's policy, according to the AAAS R&D document, implies that the country is not faced with a serious energy crisis and that the technology needed to ensure energy supply will be developed and financed by the private sector in response to market forces. The effectiveness of this approach, Teich points out, is contingent upon the ability and willingness of industry to undertake the necessary investments to achieve major technology advances and to maintain a leadership role for the United States.

Yet relying on the marketplace alone as a source of energy R&D funding can have its disadvantages. There are areas of R&D that may not attract sufficient private sector funding but would be in the best interest of the nation and the economy, such as in the areas of energy conservation and solar. And Teich warns against total reliance on the marketplace. "There is a lot to be said for using the marketplace as a mechanism for allocating R&D resources. But the marketplace is not perfect—it has distortions, such as those that result from overregulation of the nuclear industry and others that result from the quasi-monopoly positions of some of the largest energy companies, as well as the entire world oil situation." Teich cites energy conservation as an example of an area of R&D in which the market, on its own, would tend to underinvest. "Although the implementation of conservation processes and technologies (such as those DOE was pursuing) might save industries considerable amounts of money in energy use, it may not be economically feasible for an individual company to undertake the R&D needed to develop these technologies."

Therefore, to fulfill such R&D responsibilities, the private sector may have to pool its knowledge and experience to achieve national objectives. According to Teich, "The Electric Power Research Institute is one example of the type of institution that could be a model for other parts of the economy because it attempts to find common ground to pool the interests of a variety of organizations." In fact, this need for information sharing among the scientific and technical communities is integral to future R&D development—a central conclusion of both the colloquium and the R&D document.

Future R&D Trends

In the AAAS R&D document, Teich and coauthors Willis Shapley and Jill Weinberg point out four challenges created by the FY83 budget. The first is congressional passage of the budget itself, preserving the preferred treatment for R&D as much as possible.

The second challenge is to face up to the constraints on federal R&D spending. It is up to the scientific and technical community, in and out of government, to convince Congress of R&D's vital importance to the economic well-being of the nation and to set research priorities to complement administration policies. OSTP, OMB, and various other federal agencies have responsibilities in this area, as well. The authors note that the federal agencies must provide effective mechanisms to stimulate budget information exchange between the government and the research community.

The third challenge involves science and engineering education, where the role of the federal government needs to be better defined. The fourth challenge is directed specifically to industry to demonstrate that free enterprise can function in a way that will spur innovation and productivity.

The colloquium provided an opportunity to discuss these four issues face-to-face, allowing open communication among those who support research, those who perform research, and those who depend on research. It is precisely these interrelationships among the members of the administration, Congress, industry, and the scientific, engineering, and academic communities that foster the kind of information sharing needed to maintain the levels of scientific excellence and technology advancement to which the United States has grown accustomed.

As Teich concludes, "The existence of the colloquium helps policymakers recognize that there are people who maintain a continuing interest in R&D policy and helps people in the R&D community keep in touch with the changing cast of characters in policy positions. Last year, it made the transition from one set of R&D policy objectives to another a lot smoother than it might have been. It constitutes an arena for R&D policy." ■

This article was written by Ellie Hollander, Washington Office.

Technical Assessment Guide Published

EPRI document is adopted by DOE as the standard for developing cost estimates and economic analyses.

Utilities, contractors, the government, and EPRI staff can now compare R&D technology options by using the method and set of consistent premises included in the new edition of EPRI's *Technical Assessment Guide* (TAG*). The guide was developed to describe the revenue requirement method used by the Institute, its contractors, and most electric utilities to perform economic evaluations of alternative technologies and to provide a consistent set of economic factors, financial assumptions, fuel prices, and cost and performance information for use in making these evaluations.

According to George Applegren, manager of technology evaluation, Planning and Evaluation Division, this is the fourth edition of TAG and augments previous versions with an evaluation of the near-term financial impact of an option. Changes resulting from the 1981 Economic Recovery Tax Act are also included.

In addition to its use at EPRI, this edition of TAG has been adopted by DOE as a standard for constructing cost estimates and electric utility–oriented economic analyses. DOE has been given permission to reproduce the book as one of its internal source documents.

TAG is divided into two sections. The first includes a brief summary of the revenue requirement methodology, as well as data on fuel price projections and cost and performance information on transmission and generation technologies. The second section provides a more complete explanation of the economic methodology and a series of sample problems.

Copies of TAG, published as EPRI report P-2410-SR, are available from the Research Reports Center.

*TAG is an EPRI trademark.

EPRI Opens Chicago Area Office

EPRI's Nuclear Power Division officially opened a new office in the Chicago suburb of Naperville, Illinois, this month. The facility will house the division's Developing Applications and Technology Department.

The department will be headed by Clark Gibbs, formerly vice president of Middle South Energy, Inc., a subsidiary of Middle South Utilities, Inc. Gibbs will be responsible for planning, implementing, and managing the department's efforts to identify, study, and develop advanced breeder and improved light water nuclear power reactor systems. One objective will be to ensure that utility needs and concerns are addressed in the design of future breeder reactors for commercial operation.

The Chicago area office will house the Consolidated Management Office (Como), established by EPRI to participate in the breeder development program with DOE. Staffing plans are still being decided; at this time, they call for Como to include representatives from DOE, manufacturers, engineering contractors, and foreign utilities interested in liquid metal fast breeder reactor systems.

During his tenture as vice president of Middle South Energy, Gibbs also served as vice president for nuclear activities for Middle South Services, Inc., the service subsidiary of Middle South Utilities, Inc. The holding company operates electric utilities in Louisiana, Arkansas, and Mississippi

Prior to joining Middle South in 1978, Gibbs was with Commonwealth Edison

Co., where he was assigned to the Project Management Corp. PMC is a nonprofit company created to oversee the activities of the Clinch River breeder reactor project in Tennessee.

Gibbs earned a PhD in nuclear engineering from Rensselaer Polytechnic Institute and also holds a degree from the U.S. Naval Academy. For the past two years, he chaired the Atomic Industrial Forum's Committee on Reactor Licensing and Safety. ■

Loewenstein Testifies On LMFBR Safety

Walter B. Loewenstein, deputy director of the Nuclear Power Division, testified recently in Bonn, West Germany, on LMFBR safety before a Commission of Inquiry on Future Energy Policy of the Bundestag.

The commission invited Loewenstein to testify because it was considering pro and con arguments for continued funding and an operating license for the SNR-300 fast breeder, West Germany's counterpart of the U.S. Clinch River breeder reactor. The two units are counterparts in the sense that each represents its nation's first large commercial-scale demonstration fast breeder reactor.

Loewenstein was asked to comment specifically on the completeness and correctness of a study previously presented to the Inquiry Commission by the Karlsruhe Nuclear Research Center. Loewenstein corroborated the study, noting that it presents fairly the state of knowledge on reactor safety and that the open literature on sodium-cooled fast breeders had clearly been scrutinized carefully during its preparation.

"The conclusions outlined in the study are in accord with our knowledge of fast-reactor safety," Loewenstein said. "The analytic results can be duplicated essentially by a methodology identical to that used in the German safety review, as well as by related and similar methodology developed by other technical groups."

The 300-MW (e) German breeder, being built by a industry-utility team at Kalkar, near Essen, is now about 50% completed. The Inquiry Commission and the Bundestag will vote this month on completion of the project. If approved, it is scheduled to begin operation in December 1986. ■

Media Tour NDE Center

Fourteen representatives from the trade, industry, and commercial news media toured EPRI's Nondestructive Evaluation Center in Charlotte, North Carolina, in June. The center, managed by J. A. Jones Applied Research Co., evaluates and tests techniques for verifying the physical condition of power plants without damaging the components. The media tour included demonstrations of an advanced, computer-controlled ultrasonic inspection system; eddy-current inspection systems; steam turbine inspection procedures; boiling water reactor pipe inspection work; and inspections with Minac, a miniature linear accelerator used primarily for coolant pump inspections.

Matrix Management Results in Rapid Problem Solving

A matrix management system that cuts across department lines has been incorporated into EPRI's Nuclear Power Division to provide utilities with timely responses to questions about generic safety issues.

"Matrix management, which began in late 1981, is a team approach to resolving generic safety issues rapidly," says John Taylor, division director. "The teams, which can be composed of representatives from all departments within the NP Division, are usually coordinated by the Nuclear Safety Analysis Center (NSAC)."

With input from the Nuclear Regulatory Commission, utilities, owners groups, the Institute of Nuclear Power Operations, and other EPRI staff, NSAC evaluates high-consequence–low-probability generic safety issues and recommends priorities for their resolution. The issues selected are common to many nuclear power stations, require a comprehensive and sophisticated analysis, and have solutions with long-term relevance.

Once an issue is recommended and approved for assignment to a matrix management team, a timetable and budget are set, a matrix manager is selected, and team members with expertise needed for solving the problem are assigned to work full- or part-time on the team. The matrix manager coordinates the work among the various departments in the NP Division. He also serves as the main contact with the utilities to ensure technology transfer from EPRI's research and applications work.

There are now four matrix management teams working on reactor vessel pressurized thermal shock, TMI cleanup, degraded core technology, and decay heat removal. Additional teams will be formed to address problems as they arise. ■

CALENDAR

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

SEPTEMBER

21–23
Steam Turbine Disk Integrity
Minneapolis, Minnesota
Contact: Carol Verschage (415) 855-2252

22–24
Workshop: Emergency Response Facilities
Palo Alto, California
Contact: David Cain (415) 855-2112

OCTOBER

4–7
2d International Workshop: Impact of Hydrogen on Water Reactor Safety
Albuquerque, New Mexico
Contact: Loren Thompson (415) 855-2825

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

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

12–13
Performing Power Plant Reliability and Availability Analyses
San Francisco, California
Contact: Jerome Weiss (415) 855-2495

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

17–22
Decision Analysis for Utility Fuel Planning and Management
Minneapolis, Minnesota
Contact: Stephen Chapel (415) 855-2608

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

26–28
Seminar: Polynuclear Aromatic Hydrocarbons
Columbus, Ohio
Contact: Jacques Guertin (415) 855-2018

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

NOVEMBER

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

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

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

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

GEOTHERMAL ROTARY SEPARATOR—TURBINE

More electric power can be generated from a given flow of steam plus hot water from a geothermal well if the energy contained in the flow of the hot water can be used to drive a generator. EPRI has developed and tested a power conversion device called a rotary separator–turbine (RST) to produce added power from the liquid phase of the flow from a geothermal well.

The RST accepts the total two-phase flow from a geothermal well and expands the two-phase mixture through a nozzle. In passing through the nozzle, the liquid phase (hot water) continues to flash to form more vapor (steam) as the pressure drops along the flow path. The accelerating vapor reaches a high velocity and accelerates the droplets of liquid entrained in it. The high-speed two-phase jet emerging from the nozzle could be used to drive a turbine and generator directly if the liquid droplets did not tend to follow a different path than the steam in the power turbine. In the RST the two phases are separated into steam (which is sent to a conventional steam turbine) and high-speed liquid. The liquid is used to drive a specifically designed hydraulic turbine, which is built into the RST unit.

Wellhead power systems

A wellhead system consists of a power conversion unit at the site of a single geothermal well and uses the full flow from that well to produce electric power. Such a system differs from the larger (>50-MW [e]) plants that have characterized U.S. geothermal power development since Pacific Gas and Electric Co. built Unit 5 at The Geysers in 1971.

Wellhead geothermal power systems have attracted interest over the past two years as electric utilities look for ways to become involved early in the development of geothermal reservoirs and to acquire operating data useful for evaluating reservoirs and planning expansion. The EPRI staff estimates that about 5% of the known hydrothermal resource base of 24,000 MW (e) will be developed by using such wellhead units in sizes less than 10 MW (e). This will be an important 5% because it will, for the most part, represent new starts at new fields. On November 10, 1981, a 1.6-MW (e) rotary separator–turbine became the first geothermal wellhead power system in the United States to produce electricity for a commercial utility distribution network. It was tested in 600 hours of operation and produced electricity for Utah Power & Light Co. (UP&L).

Although wellhead units have been installed in Italy, the Philippines, and Indonesia, these are steam turbines that run on steam after the steam has been separated from any liquid fraction that may be produced along with the steam. A complete wellhead power system using the concept tested in Utah would include a steam turbine alongside the RST to produce power from the steam as well as from the RST. When a steam turbine is added to the system, the total power output of the RST plus the steam turbine will be about 15% greater than the power output of a steam turbine alone.

The RST in Utah is the first EPRI wellhead power conversion project. The five-year plan for the EPRI Geothermal Power Systems Program includes installation and testing of one or two other types of wellhead power systems. It is anticipated that these projects will be cost-shared with electric utility companies or other industry partners.

Description of an RST

The RST tested and now installed on the UP&L system has the following primary components (Figure 1).

- Four nozzles, each of which receives a quarter of the total flow from a geothermal well and converts part of the thermal energy of the inlet fluid into kinetic energy of a high-speed jet.

- A separator rotor captures the liquid on the rim of a rotor, and separates the steam flow from the liquid flow.

- A liquid turbine scoops the rotating liquid off the rim of the separator and reverses its direction of flow through two U-tubes, thereby producing torque to drive a generator.

- A liquid transfer rotor receives the liquid discharge from the U-tubes and keeps the liquid on the rim of a rotor so that it can be picked up by a stationary diffuser.

- A stationary diffuser scoops the liquid off the transfer rotor, recovers pressure from the kinetic energy of the liquid, and discharges a pressurized stream of liquid for injection back into the geothermal reservoir.

Performance tests

The RST (Figure 2) arrived at the UP&L test site near Milford, Utah, on September 16, 1981, and first produced electric power on October 28. Power was delivered to the UP&L system on November 10, 1981. Problems with the lube oil system prevented operation at design housing pressure (50 psia; 345 kPa) until December 1981. Data useful for mapping the performance of the unit were first obtained in December, and

Figure 1 After separation from the steam in the centrifugal force field on the rim of the separator rotor, the liquid water flows through the unit and gives up some kinetic energy to provide power output to the turbine shaft. The flow and energy transfer are made possible by the different speeds of the three rotors. In the test run that produced the maximum power, these speeds were 3126, 1800, and 425 rpm (52, 30, and 7 Hz) for the separator, U-tube turbine, and liquid transfer rotors, respectively.

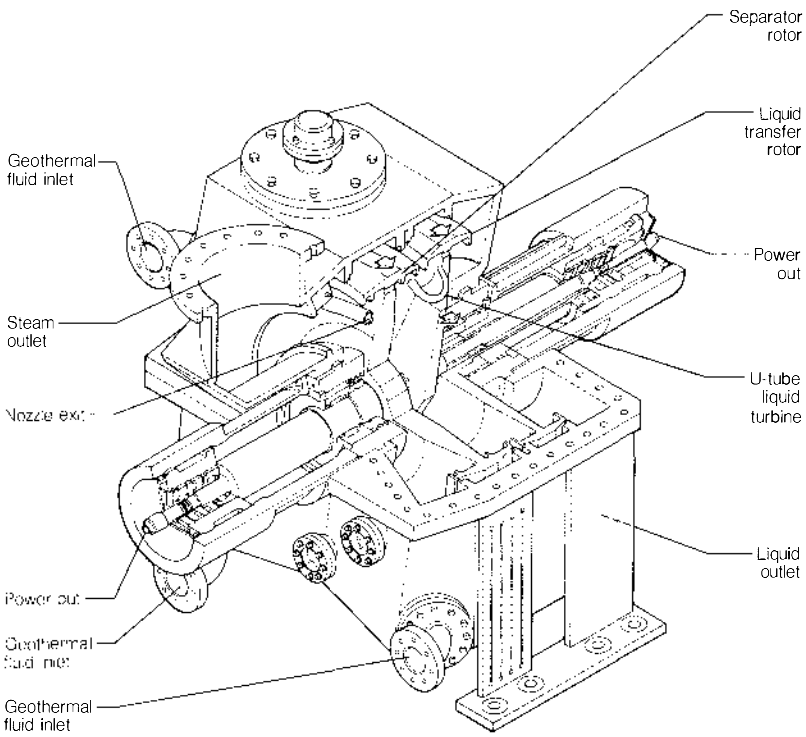


Figure 2 RST wellhead power system installed at the Roosevelt Hot Springs geothermal field near Milford, Utah. The skid-mounted 1.6-MW (e) system was delivered to the site on September 16, 1981, and first produced electric power on October 28. If a steam turbine is added to the system, about 7 MW (e) could be produced from the 500,000-lb/h (63-kg/s) flow from the well.

performance testing continued through January 1982.

During this period the RST produced 294,000 kWh gross and delivered 125,000 kWh net to the UP&L system. Much of the electricity produced, especially during the earlier part of the testing, was deliberately put into a load bank rather than on the UP&L grid. On January 31, 1982, the well was shut in order to install permanent equipment at the site. The permanent equipment will be part of the steam supply system for a 20-MW (e) direct-flash power plant being built for operation in 1984 by UP&L. Testing of the RST at the same well resumed in August 1982.

UP&L is the host utility and cofunder with EPRI of the wellhead RST field test. The contractor for the testing of the RST concept is Biphase Energy Systems of Santa Monica, California. Biphase is also sharing the cost of the project and paid for fabrication of the 1.6-MW (e) RST system now installed at the Roosevelt Hot Springs geothermal field near Milford, Utah. Biphase is a wholly owned subsidiary of two companies, each a 50% partner in the joint venture: Research Cottrell of Somerville, New Jersey, and Transamerica Delaval of Lawrenceville, New Jersey. The geothermal field at Roosevelt Hot Springs is operated by Phillips Petroleum Co., on behalf of itself and three other companies holding geothermal development rights in the area: Amax Exploration, Thermal Power, and O'Brien Resources.

The design specifications for the wellhead RST are given in Table 1, along with some results from the measurements of actual performance from a run at maximum power output conditions. To evaluate the capability of the RST under the full range of conditions that could arise at Milford or at other geothermal sites, data were obtained at nozzle inlet pressures ranging from 210 to 470 psia (1.4–3.2 MPa), outlet steam pressures from 30 to 60 psia (207–414 kPa), and operation with 1, 2, 3, and 4 nozzles. Performance maps are being developed to show both total power output and resource utilization efficiency, which measures how well a system converts a given amount of geothermal heat into electricity. Resource utilization efficiency is shown in Table 1 as ratio to one-stage flash. This is the ratio of power output from a system consisting of both an RST and a steam turbine to the power output of a system having only a steam turbine.

RST system for other geothermal resources

RSTs operating at different conditions will have the same basic housing and rotors.

Table 1
RST TEST AT MILFORD, UTAH
DESIGN PREDICTION AND TEST RESULTS

	Design		Measured	
Nozzle inlet				
Pressure (psia; MPa)	400	2.76	343	2.33
Temperature (°F; °C)	445	229	430	221
Flow (1000 lb/h; kg/s)	515	65	451	57
Steam fraction (%)	8.2		8.1	
Steam outlet				
Pressure (psia; kPa)	50	345	43	296
Temperature (°F; °C)	281	138	272	133
Flow (1000 lb/h; kg/s)	119	15	108	14
Power production				
Liquid turbine (kW)	1635		1010	
Steam equivalent (kW)	5545		5160	
Total (kW)	7180		6170	
Comparison, one-stage flash (kW)	6260		5510	
Efficiency				
Ratio to one-stage flash	1.15		1.12	
Nozzle	0.79		0.64	
RST overall	0.37		0.27	

Optimal performance will be achieved by interchanging nozzles, U-tubes, and stationary diffusers. Although nozzle efficiency is the most critical factor, flow parameters can also be adjusted to help RST operation at off-design conditions.

The actual resource utilization efficiency measured at Milford last December and January (Table 1) is below the design value because the nozzle used was designed for 400 psia (2.8 MPa) inlet pressure, the expected wellhead pressure, while the actual nozzle inlet pressure at the design flow rate was only 343 psia (2.3 MPa). Reworking of the well during the spring of 1982 is expected to result in wellhead flow and pressure at the design values when the RST endurance tests resume at Milford. If this improvement is not as expected, the nozzles in the RST will be replaced with a set designed for lower inlet pressure.

In general, resource utilization efficiency relative to a steam turbine system declines with temperature because the RST nozzles become less efficient. The ratio also declines at higher temperatures because the optimal single-entry (one-stage flash) pure-steam turbine system at these higher temperatures and pressures becomes increasingly efficient compared with the RST, thereby decreasing the relative amount of power to be gained by adding an RST. *Project Manager: Evan Hughes*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

EVALUATION OF FULL-SCALE FGD SYSTEMS

EPRI initiated a flue gas desulfurization (FGD) system characterization project (RP1410) to develop data to assist electric utilities in optimizing the operation of existing wet scrubber systems, to aid in the selection of new scrubber systems, and to enable informed responses to possible new emission requirements. The project entails extensive, detailed evaluations of the emission control capabilities of selected representative full-scale wet scrubber systems currently in operation. The scrubber systems that have been characterized are those of Columbus and Southern Ohio Electric Co.'s Conesville Unit 5 and Montana Power Co.'s Colstrip Unit 2.

The selected scrubber systems were characterized by field testing and engineering analysis. Measurements were performed for currently regulated emissions and several unregulated emissions in the gas, liquid, and solid streams of the scrubber systems. Concentrations of sulfur dioxide (SO_2), nitrogen oxides, particulate, fine particulate (<2 μm diameter), trace elements (including distributions by particle size), sulfuric acid mist, chlorides, fluorides, organics, carbon dioxide, and carbon monoxide were measured in scrubber influent and effluent streams. In addition, mist eliminator performance, scrubber-generated particulate, and scrubber sludge measurements were conducted.

These measurements, combined with scrubber process chemistry information, operating data, and design characteristics, provide a detailed understanding of the performance of the scrubber systems. Material balances and other techniques for establishing data consistency and reasonableness were applied in an effort to identify the quality and limitations of the data collected. Areas in which potential improvements in scrubber operation could be made have been identified.

Scrubber systems

Conesville Unit 5 is a 411-MW power plant that began operation in January 1977 and burns high-sulfur eastern coal. The unit's air quality control system consists of an electrostatic precipitator (ESP) followed by an FGD system. The cold-side ESP is designed to remove 99.65% of the particulate matter to comply with the applicable federal New Source Performance Standard (NSPS) of 0.1 $lb/10^6$ Btu of heat input. The FGD system is designed to remove a minimum of 90% of the SO_2 and meet a state SO_2 emission limit of 1.0 $lb/10^6$ Btu, which is more restrictive than the applicable NSPS (1.2 $lb/10^6$ Btu).

The FGD system at Unit 5 consists of two turbulent contact absorber (TCA) scrubber modules. These rubber-lined carbon steel vessels each have one level (6–8 in deep; 15.2–20.3 cm) containing mobile spheres (1.5 in diameter; 3.8 cm) to provide a turbulent contacting area for SO_2 removal. Lime containing 3–5% magnesium is the SO_2 removal additive.

Colstrip Unit 2 is a 358-MW plant that fires low-sulfur western coal. It began operation in July 1976. The unit's air quality control system consists of a variable-throat venturi–spray tower scrubber, which removes both particulate and SO_2. The scrubber is designed to comply with state and federal particulate emission limits of 0.1 $lb/10^6$ Btu and a stack plume opacity limit of 20%. The system is also designed to meet state and federal SO_2 emission limits of 1.2 $lb/10^6$ Btu. Unit 2 is served by three scrubber modules with no flue gas bypass capability. At Colstrip, as at Conesville, the evaluation focused on one scrubber module.

Conesville: conditions and results

Test condition variations at Conesville were determined in part by experimental design and in part by operational constraints. The variables selected for investigation included boiler load, flue gas flow, and liquid-to-gas (L/G) ratio (the ratio of slurry flow to the flue gas flow). Significant variations resulting from scrubber operational changes were experienced for pH and the lime reagent ratio (the molar ratio of the calcium and magnesium used to the sulfur removed).

Testing was conducted over a range of boiler load conditions (60–100%) to obtain variations in the gas flow to the scrubber and thus enable significant changes in emissions resulting from differences in load to be characterized. However, because of variations in excess combustion air, flue gas bypass, and the number of scrubber modules in service, only a relatively small variation in flue gas flow to the test module was experienced. The scrubber recycle slurry flow was varied during the test to establish a range of L/G ratios of about 35–70 gal/1000 actual ft^3 (0.0046–0.009 m^3/m^3). Variations in this flow were accomplished by using two, three, or four recycle pumps (three is typical). The reagent ratio varied from about 1.0 to 1.3. The scrubber slurry operating pH ranged from about 6.0 to 7.5.

Average SO_2 removal efficiencies for all tests ranged from 95.3 to 99.2% (Table 1). Generally, the higher removal values corresponded to higher L/G ratios. However, the SO_2 removal range was considered too narrow and too near 100% to establish a quantitative relationship. The pH and the reagent ratio were also important in SO_2 removal. The SO_2 data for each test were taken over

Table 1
FLUE GAS SO_2 CONCENTRATIONS AND SO_2 REMOVAL EFFICIENCY FOR CONESVILLE SCRUBBER MODULE

	Inlet SO_2			Outlet SO_2			
Test	Volume (ppm)	Weight per Fuel Value (ng/J)	Weight per Fuel Value (lb/10^6 Btu)	Volume (ppm)	Weight per Fuel Value (ng/J)	Weight per Fuel Value (lb/10^6 Btu)	SO_2 Removal (%)
1	2370	2200	5.12	19	18	0.04	99.2
2	2220	2110	4.92	23	22	0.05	99.0
3	2430	2330	5.41	46	45	0.10	98.1
4	2380	2220	5.17	18	17	0.04	99.2
5	2710	2950	6.86	79	88	0.20	97.1
6	2800	3490	8.11	80	100	0.23	97.2
7	3060	3490	8.11	142	164	0.28	95.3

Note: SO_2 levels by volume were determined by averaging continuous-monitor data (dry basis). Levels by weight per fuel value were calculated by using a factor representing a ratio of the volume of dry flue gas generated to the calorific value of the fuel burned (EPA F factor method). This factor was adjusted to the actual excess air present in the flue gas as determined by the oxygen content. SO_2 removal values are based on the SO_2 levels given in lb/10^6 Btu.

a controlled period of approximately one day and do not necessarily reflect long-term control and operation of the module.

The scrubber generally provided some additional particulate removal (10–90% of the particulate remaining in the flue gas coming from the ESP) as determined by EPA Method 5, the reference method for particulate measurement. The scrubber appeared to have a significant impact on emissions of sulfuric acid, hydrochloric acid, hydrofluoric acid, and most trace elements and to have a negligible impact on emissions of nitrogen oxides, carbon monoxide, and organic materials. The presence of condensed sulfuric acid created significant problems in fine-particulate sampling and the measurement of trace elements by particle size. Significant improvements in the techniques for making these measurements (and also for measuring organics) are needed before reliable information can be collected.

Several potential scrubber operational improvements were identified as part of the evaluation of the Conesville Unit 5 scrubber system. One involves removal of all or part of the TCA mobile sphere packing to permit increased gas flow through the scrubber or to reduce the system pressure drop. The utility estimated that the cost savings for Unit 5 resulting from this change would be about $22,500 a year in fan operation costs and about $128,000 a year in maintenance and mobile sphere replacement costs. The TCA mobile sphere packing has subsequently been removed from all scrubber modules of Units 5 and 6. Preliminary tests performed by the utility on one of the modules indicate a reduction in pressure drop with acceptable SO_2 removal efficiency. The utility has reported that the elimination of plugging problems in the mobile sphere bed area has resulted in reduced scrubber maintenance and improved availability.

Another potential operational improvement involves reducing pumping power requirements and scrubber pressure drop by operating with only two recirculation pumps and reducing the amount of slurry recirculated. This modification may not be feasible, however, since the TCA mobile packing spheres have been removed.

A third potential improvement involves modification of the mist eliminator system by adding a bleed line to the recirculation tank and by pretreating the slaking dilution water to maintain suspended solids and silica at acceptably low levels. These modifications should help minimize nozzle pluggage and mist eliminator scaling.

Colstrip: conditions and results

All of the Colstrip Unit 2 scrubber testing was conducted at nearly full power because of high load demands on the units. The principal variations in test conditions involved increasing the recycle slurry solids content up to a level of about 18% from the routine operating level of 10–12% and operating without adding lime to supplement the alkaline fly ash collected in the venturi–spray tower scrubber.

The overall SO_2 removal efficiency of the scrubber module tested was 83–88%. Process chemistry measurements and calculations suggest that roughly one-half of the SO_2 was removed in the wash tray–mist eliminator section. The Colstrip Unit 2 scrubber showed an overall particulate removal efficiency of 98.2–99.1%.

The scrubber appeared to achieve at least some reduction in fine particulate emissions and in trace element emissions as a function of particle size. Little impact was seen on emissions of nitrogen oxides, carbon monoxide, and organics. The amounts of sulfuric acid, hydrochloric acid, and hydrofluoric acid at the module inlet were so low that the estimated system removal values were not meaningful. There were fewer sampling problems at Colstrip than at Conesville, but the need for improvements in sampling techniques was still indicated.

Evaluation of tests

Conclusions based on the characterization of the Conesville and Colstrip SO_2 scrubber systems should be viewed from two perspectives: emission control and system performance.

Both scrubber modules evaluated seem to be capable of achieving, at least in the short term, SO_2 removal efficiencies greater than those required by current NSPS regulations. Also, on the basis of the inlet concentrations measured during these tests, both the Conesville and Colstrip emission control systems appear to be capable of significant particulate removal. It is uncertain, however, whether either system as designed (the ESP and wet scrubber at Conesville or the venturi–spray tower absorber at Colstrip) would meet the current particulate NSPS.

The Conesville scrubber system provided high SO_2 removal across the module, but the presence of a gas bypass essentially controls the overall system SO_2 emissions. The high-magnesium lime provides the capability of very high scrubber module SO_2 removal. Calculations indicated that because of the high alkalinity of the slurry, the mobile contacting spheres in the absorber could be removed without significantly affecting SO_2 removal. As noted above, the utility has since removed the spheres in Units 5 and 6 with no apparent degradation of SO_2 control. Another operational improvement would be to reduce the

L/G ratio in the scrubber by reducing the amount of recirculating slurry. Testing confirmed that a 50% reduction in this ratio had a minimal impact on SO_2 removal. These changes can result in significant energy and cost savings for any utility using or considering such a scrubber system.

A potentially important design impact was identified at Colstrip when calculations indicated that the mist eliminator system might be removing significant amounts of SO_2 as a result of the chemical removal mechanism (oxidation) and the presence of a significant mass transfer area. An examination of fly ash for the presence of oxidizing agents, such as manganese, and an evaluation of mass transfer capabilities and scrubber process chemistry could provide insight into design improvement and better use of the high alkalinity of fly ash from some coals.

Also identified for both scrubber systems were areas where scaling might occur and techniques for avoiding this problem. These techniques can be applied to any wet scrubber to reduce the operating costs resulting from maintenance outages.

Scrubber-generated particulate (slurry entrainment) did not appear to be significant in either of the scrubbers; however, there was a significant difference in the measured moisture removal efficiencies of the mist eliminator systems. This difference suggests the need for further research to ensure proper design and operation of such systems.

Both units appear to be fairly typical of currently operating wet scrubber designs. Conesville had low system availability during the first few years of operation, but availability was substantially improved during 1981 and current values approach 90%.

It was concluded that the sampling and analysis techniques used at the two test locations could provide significant insights in the evaluation of any FGD system to aid in troubleshooting and in optimizing system operation. Future studies of this type are expected to be most profitably directed at units experiencing operational problems. Several problems were encountered while collecting data on a wide range of currently unregulated emissions. There were difficulties in achieving material balance closures, and the results on concentrations of trace elements, fine particulate, and organics were inconsistent. These problems emphasize the need for the development and demonstration of improved sampling and analysis methods for these species. *Project Manager: Richard Rhudy*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Updated transmission line reference book

An updated, expanded edition of the *Transmission Line Reference Book, 345 kV and Above* has just been published (Figure 1). The 625-page book, widely known as the red book, is intended as a source of technology and data for the electrical design of EHV and UHV transmission lines up to 1500 kV. This second edition represents a substantial expansion in the technical content of each of the topics covered in the first edition (published in 1975) and contains five years of new test results. The broader scope of the new edition makes the reference book more valuable to the beginning engineer, as well as to the experienced designer. The addition of a new chapter that summarizes the book and presents line design in a tutorial style contributes to the second edition's effectiveness. In fact, anyone who has not had extensive experience with the first edition should start the second edition by reading Chapter 13.

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 a base case circuit design is analyzed to help the design engineer understand and become sensitive to the items affecting design. Means to measure each performance factor are also fully explored.

The book may be ordered through the Research Reports Center. Copies will be provided without charge to EPRI member utilities; the price for nonmembers in the United States, Canada, and Mexico is $55.00. Outside North America, the price is $110.00. *Program Manager: Richard Kennon*

Figure 1 The new edition of the *Transmission Line Reference Book*.

Polysil* insulators

One primary concern about any new material is its performance in the field over its expected service life. Most transmission line engineers can cite examples of panaceas that looked good on paper and in the laboratory but did not perform well in the field. Field testing, therefore, is an important step in the introduction of any new material, and Polysil is no exception. Although the material has performed well under industry-accepted testing methods and Polysil insulators have equaled or out-performed their counterparts made from ceramic materials, a demonstration of favorable long-term field performance would increase the industry's confidence in this new insulator. If Polysil insulators do gain acceptance, considerable cost savings may be achieved by utilities.

To provide information on the in-service performance of these insulators, 25 racks, each containing 17 different designs of Polysil insulators, are under test in widely varying climatic and contamination conditions. A major objective of this experiment is to determine how shape, coating, material, and/or voltage grading will affect performance of the insulator. The evaluation effort will last three years, and the final results will be reported by the University of Southern California in mid-1984 (RP1281-2).

Most of the racks have now had about one year of service, so only preliminary results can be reported at this time. So far, all the Polysil designs are performing well as outdoor insulators. Hopefully, as contamination accumulates on the insulators, the advantages of certain designs will become

*Polysil is an EPRI trademark.

apparent. The coating on a few insulators has discolored or flaked; however, this is not adversely affecting their performance. The reason for changes in the coating on these few insulators is being investigated.

Through the cooperation of the utilities hosting the Polysil racks, an additional two years of exposure will be obtained; then the final report giving detailed performance data and analysis will be issued. *Project Manager: John Dunlap*

UNDERGROUND TRANSMISSION

Dc transmission cable

BICC Supertension Cables, Ltd., of England has recently completed work on a project (RP7859) to establish the maximum attainable design voltage for dc cables (when insulated with oil-impregnated cellulose-paper tapes). The final report will be available later this year. This work was geared specifically to pressurized-oil systems of the low-pressure, self-contained, oil-filled (SCOF) and high-pressure, oil-filled (HPOF) varieties.

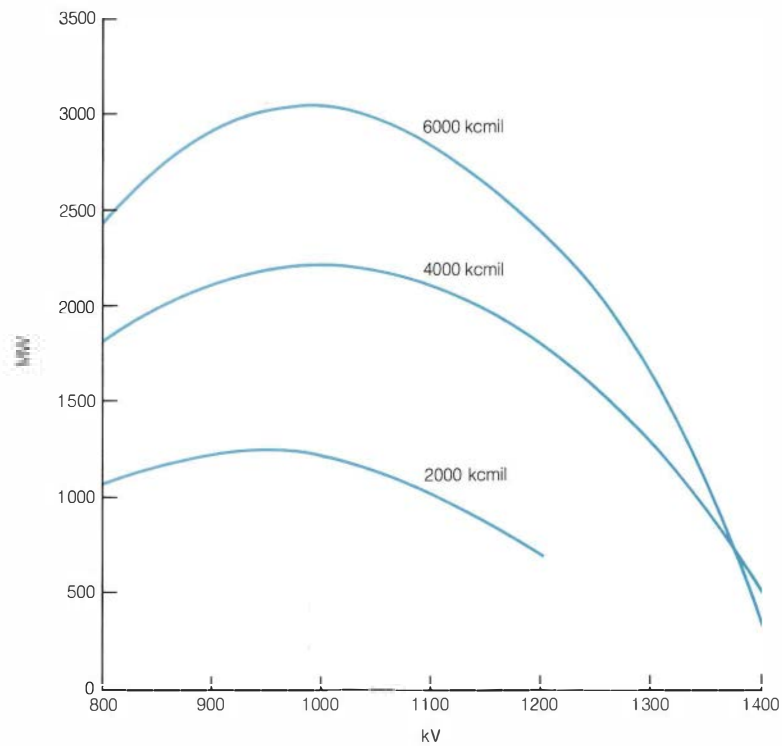
This project was funded because it was thought that by the end of this century, transmission systems rated in excess of 1000 kV might be needed. At that time, as now, oil-impregnated, cellulose paper was the only proven dc cable dielectric. The highest voltage dc cable then available was rated ±300 kV; hence, it was necessary to determine whether this material would be suitable for the 1000-kV range.

The effects of the electrical, mechanical, hydraulic, and thermal parameters of these large cables on their manufacture, transportation, installation, and operation were investigated. The principal constraints to achieving highest voltage and power ratings were found to be the combination of the following.

- Maximum withstand voltage gradient under polarity reversal conditions
- Minimum permissible cable bend diameter
- Maximum permissible shipping reel diameter

Allowing for these constraints, the maximum power and voltage ratings for HPOF cables are as given in Figure 2; the ratings for SCOF cables are very similar. The conclusion is that oil/paper-insulated cables rated in excess of ±1000 kV are feasible. When the need becomes more imminent, it will of course be necessary to develop and test prototypes of these cables. *Project Manager: Felipe G. Garcia*

Figure 2 Maximum attainable power and voltage ratings per pole for various conductor sizes.



DISTRIBUTION

Effect of voltage on energy conservation

Since the last status report on this project (March 1981), a report was published on the testing of individual load components (EL-2036). The results of these tests showed that the energy consumption of some loads definitely depends on the operating voltage. Energy consumption may increase or decrease, depending on operating conditions and voltage levels. In this first phase of the project, a preliminary assessment was also made of the energy consumed by typical load mixes, as determined by a survey conducted in a previous EPRI project (RP849). This assessment indicated that a small energy reduction might result from a voltage reduction.

EPRI is now working on a feeder energy model that can be used to quantify energy consumed as a function of feeder voltage. Lowering the feeder voltage, as advocated by energy conservationists, means lowering only the high end of the allowable voltage band; thus, instead of a band of 126–114 V, a band such as 120–114 V is advocated. The model is built to determine how much energy is used with any given voltage band. Whether the system changes that are needed to lower the upper range of the voltage band could ever be justified by the energy savings is a separate topic to be addressed later in the project.

With voltage reduced as just described, the change in energy consumption is very low, so low, in fact, that it is masked by the random variations that are characteristic of normal operation. A host of variables are constantly modifying energy consumption from hour to hour, day to day, season to season. Thus, very comprehensive voltage reduction experiments on operating systems are being performed to gather adequate data for determining the true voltage-energy relationship needed to verify the model.

Two utilities, Texas Electric Service Co. (Tesco) and Detroit Edison Co., are participating by conducting controlled-voltage experiments. Each utility has selected six residential areas, three commercial areas, and three light-industrial areas for studies. Three of the residential areas are in a development that consists primarily of all-electric homes, and the other three are in a development where the percentage of all-electric homes is relatively low. The commercial areas have similar load characteristics, as do the light-industrial areas.

The homogeneity of the loads within the respective test areas minimizes the effects of some natural variables, thereby allowing the separation of the energy change due to voltage variations from the random variation with greater confidence. The resultant voltage-energy data will be used to verify the energy model.

The first workable energy model will probably not be an easy one to use because it will be too detailed, requiring too much input data, which a utility would not be expected to have readily available. We are making sensitivity studies to determine where the model can be simplified without destroying its accuracy. The objective is to arrive at a code that can be used on commonly available digital computers to predict energy consumed on a feeder as a function of voltage, without requiring more than commonly available information for input.

Success with the preliminary stages of model development indicates that a convenient and faithful model can be produced. Work on the model, the sensitivity analyses, and subsequent simplification will continue in parallel with the field experiments. To observe the full spectrum of seasonal load variations, one year of field experiments have been scheduled. It will be mid-1983 before these are completed, after which a final report will be issued. *Project Manager: Herbert Songster*

Destructive failure of distribution transformers

Conventional distribution transformers use oil as a dielectric and as a heat transfer medium. Transformers that use solid organic insulation are available, but they have limited overload capability, which limits their application. If mechanical or electrical failure causes an arc to form in an oil-filled transformer, the sudden pressure rise can result in tank or bushing failure, thus discharging hot or burning oil. Methods to eliminate this type of failure, such as strengthened tanks, pressure relief valves, and current-limiting fuses, have not been entirely successful or cost-effective. Hence, a research project was initiated to eliminate the disruptive effect by eliminating the oil and using other materials to accomplish its functions (RP1143-1).

The objective of this project was to develop an oilless distribution transformer design that has the same rating structure, cost, losses, and size as a conventional oil-filled transformer. It could thus be a direct replacement for popular pole-mounted and pad-mounted applications. If oil is eliminated, the primary heat transfer mechanism between the coils and the transformer tank is radiation. Preliminary calculation showed that radiation cooling to the tank wall could result in winding hot spot temperatures on the order of 350°C. This temperature was shown to be acceptable for the core steel and conductors, but it would require new approaches for the insulation system. The turn-to-turn insulation was felt to be the most challenging. Several inorganic insulation systems that can withstand this temperature and that are suitable to transformer manufacture were developed. Model transformer coils were built to test new designs, materials, and methods. The results were sufficiently encouraging to warrant a follow-on project (RP1143-2) to design and construct a limited number of 25-kVA pole-mounted distribution transformers for demonstration and test on utility systems. *Project Manager: Joseph W. Porter*

Distribution, communication, and load management

Electric utilities have a great deal to gain from a distribution, communication, and load management system. Key to the success of such a system would be wide application of an efficient, reliable, and versatile communication network. Broadcast radio offers this potential because it could provide two-way communication for large areas at attractive data rates. Further, its inherent low cost would be particularly desirable for automated distribution and load management functions. In 1982 EPRI completed a two-year feasibility study of a two-way AM/VHF broadcast radio system designed for utility use by Altran Electronics, Inc. The Southern California Edison Co. acted as a host utility to test the system. Because of the success of a demonstration in this project, a major 1000-point communication network will be installed and evaluated by the Philadelphia Electric Co. (RP1535).

An effective utility distribution automation system should be capable of two-way communication with numerous control and monitoring points. As with load management applications, a low installed cost per point and high reliability of transmission media (in both directions) are very important.

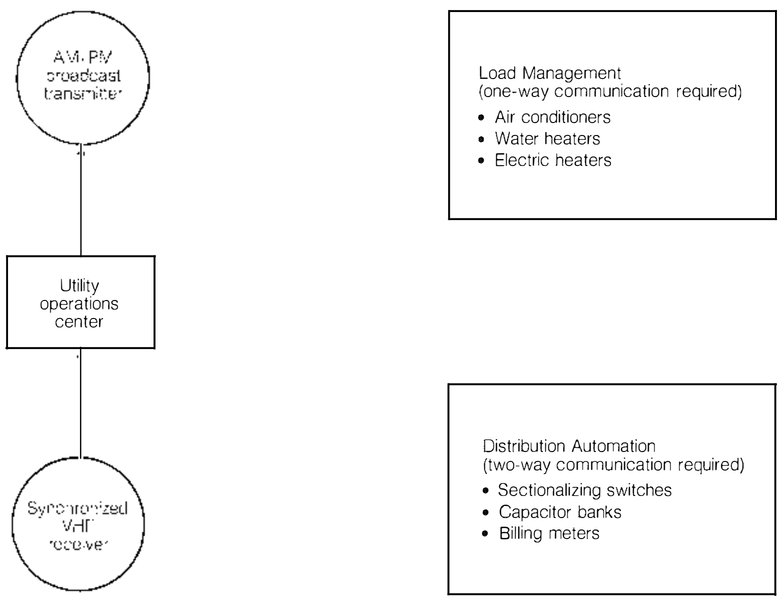
Figure 3 shows how Altran's control commands are generated at the utility control center by using a computer-based energy management console. Messages are sent to an AM radio station transmitter through a leased data line or microwave link. Forward-link messages are transmitted from the AM broadcast transmitter to diverse customer and distribution system locations. From these locations, status and measurement data are sent to the utility central receiver via a new synchronized VHF return link. Microwave or leased data links can be employed to connect the central receiver to the utility control center.

The unique communication concept employed involves synchronizing a network of receivers (and, in some applications, return-link transmitters as well) to the highly reliable and accurate radio carrier frequency of an existing AM broadcast station. The forward-link digital signals are superimposed on the broadcast signal in a noninterfering manner and are communicated at 16 bits per second to remote load-switching receivers. Since high-power AM stations have ranges of over 100 mi (161 km), one broadcast station can usually cover all the utility's service territory.

The forward communication link uses the unused RF carrier power of AM broadcast stations without interfering with the audible signal, which needs no more than 33% of the carrier power. The proposed modulation process uses a substantial part of the remaining 67% to signal load management receivers over an area of more than 30,000 mi² (77,700 km²) from a high-power AM broadcast station. The return data link consists of a VHF transmitter at each customer location that is synchronized with the central radio receiver. Consequently, the receiver can provide several narrow-band subchannels, which, in turn, improve the signal-to-noise ratio and channel utilization of the return link by a very large factor. Consequently, data can be returned at a rate exceeding 1000 bits per second.

A flexible utility load management system should be capable of communicating with many control points, have a low installed cost per control point, and have a high degree of reliability (not only of device hardware but also of the employed communication media). A high degree of reliability minimizes maintenance costs and avoids the substantial costs resulting from inoperative units, which is aggravated during periods of

Figure 3 Applications of two-way radio communications. The forward (control) link of this system uses commercial broadcast radio. Utility phase-modulated (PM) digital signals are added to amplitude-modulated (AM) broadcast information. Standard AM receivers cannot detect the utility signals and vice versa. The return data link uses VHF receivers that are synchronized by the broadcast station to significantly increase data rate and coverage range.



peak demand. Many utilities have concluded that radio load management is inherently cost-effective for systemwide applications, especially where there are many devices spread out over a large geographic area.

The Altran load management control receiver operates in the AM broadcast band and contains fewer and more reliable components than radio receivers operating in higher frequency bands. It is, therefore, in an advantageous position to meet the utility objective of low overall cost per point, controlled with a high degree of reliability.

There are seven features of AM broadcast radio that make it attractive.

- Relative freedom from jamming and tampering
- Capability to cover a large geographic area
- Potential high-communication (broadcast) signal reliability
- Freedom from signal blocking by adjacent channel radio services (no station licensing constraints)
- Flexibility in receiver location
- Emergency communication if lines are down or substation is damaged
- Lowest projected equipment cost and installation cost

The AM broadcast carrier is used as a reference for frequency and time to synchronize the two-way communication system. In this way, reverse-link transmissions (from distribution system control points to the utility central receiver) can be sent over VHF channels with greatly improved channel utilization, which permits dozens of independent transmitters to operate simultaneously.

The EPRI-sponsored demonstration of this concept at Philadelphia Electric should substantiate application of this technology to make more efficient use of the frequency spectrum available for transmission of data. In addition, the superiority of the technology for transmitting digital data from low-cost, return-link transmitters used in load management or distribution system automation functions should be revealed. *EPRI Project Manager: William Blair*

Thermal overload characteristics of extruded dielectrics

Allowable emergency operating temperatures for extruded dielectric distribution cables have been the subject of much scrutiny in recent years. These cables (rated 5–69 kV) may possess one of several polyolefinic-type insulations: high-molecular-weight polyethylene, cross-linked polyethylene (XLPE), or ethylene propylene rubber (EPR). They are designed and constructed with the objective of achieving satisfactory operation in wet or dry locations at elevated conductor temperatures. In general, where elevated temperatures are concerned, the use of the cross-linked insulation, XLPE or EPR, is encouraged, and it is these two types of insulation that have generated much discussion.

The definition of emergency operation is provided in the industry specification "Insulated Shielded Power Cables Rated 5 Through 69 kV," developed by the Association of Edison Illuminating Companies (AEIC-CS5-81 and CS6-79); this states that conductor temperatures for the cables are not to exceed 90°C for normal operation, 130°C for emergency operation, and 250°C for short-circuit operation. The specification further states that the emergency operating temperatures are applicable "for an average, over several years, of one period of not more than 36 hours per year for cables rated 5 to 46 kV and not more than 72 hours per year for cables rated 69 kV, but for a total of not more than three periods in any 12 consecutive months." The reason for these limitations is the concern that cable failure might result if the cable is operated at an elevated temperature for too long a period of time. Failure could result from physical changes in the insulation at elevated temperatures, leading to instability at the insulation-shield interfaces, or even changes within the insulation itself caused by prolonged thermal stress.

Evaluation of performance behavior is a complex subject; XLPE and EPR insulation, although apparently behaving similarly at ambient temperatures, respond quite differently in the 90–130°C region. Cross-linked polyethylene is semicrystalline in nature and undergoes a melting transition in that temperature range; the polymer is coherent under these conditions because of its cross-linked nature, but the melting transition is accompanied by a substantial degree of thermal expansion. The EPR compound, being rubbery initially, undergoes no such change (unless it was initially compounded with some polyethylene) and remains coherent, not only because of the cross-linked nature but also the presence of inorganic mineral filler (which reduces thermal expansion characteristics).

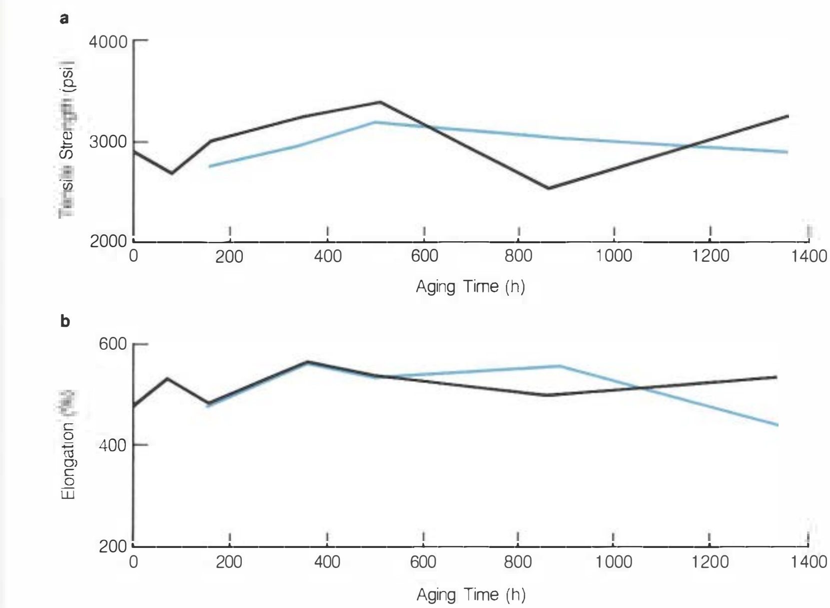
These physical changes, while significant from a materials perspective, may not necessarily always be relevant to real-world operation if the cable emergency operating temperatures (which, by the AEIC definition, relate to conductor, not insulation, temperatures) are reached but not maintained. Hence, a conductor temperature of 130°C for 5 seconds versus a conductor temperature of 130°C for, say, 24 hours would be expected to induce significantly different responses within both the cable insulation and the total cable construction. Further, different insulation thermal conductivities would lead to different cable insulation physical responses, even after similar overload times. Certainly, prolonged intervals at the high temperatures could influence the insulation thermal expansion, the semiconducting shield-insulation interfaces, and the shield materials themselves. The metallic tapes might penetrate the insulation shield under prolonged overload conditions. As a result, the establishment of allowable thermal overload requirements represents a composite of aspects, including cable construction, insulation nature, shield nature, metallic shield construction, and total time under overload.

As described in previous R&D Status Reports, an earlier EPRI project focused solely on the aspect of the insulation materials (RP933). The final report is now available and has been referenced by others in the field concerned about this problem (EL-938). A current project (RP1516) with Cable Technology Laboratories (CTL) is focusing on the cable and was discussed in an earlier *Journal* article (September 1980, p. 37).

The CTL work is focusing on a variety of insulation materials and cable constructions; one area relates to the influence of the metallic shield on the insulation during thermal overload, and a variety of shield constructions are to be evaluated (copper wires, tapes, and ribbons). The method by which copper ribbons are used would be expected to have minimal impact on the insulation, while tapes (which are commonly used) might be most severe.

Early in the project, CTL procured a number of 15- and 35-kV cables of varied construction, all of which were required to meet the overall AEIC specification. After confirming AEIC requirements, experimental work was performed with cables composed of

Figure 4 **(a)** Tensile strength and **(b)** elongation at breakdown of XLPE insulation compared with oven-aging time at 175°C. Black curve: outer part of cable insulation; color curve: inner part of cable insulation.



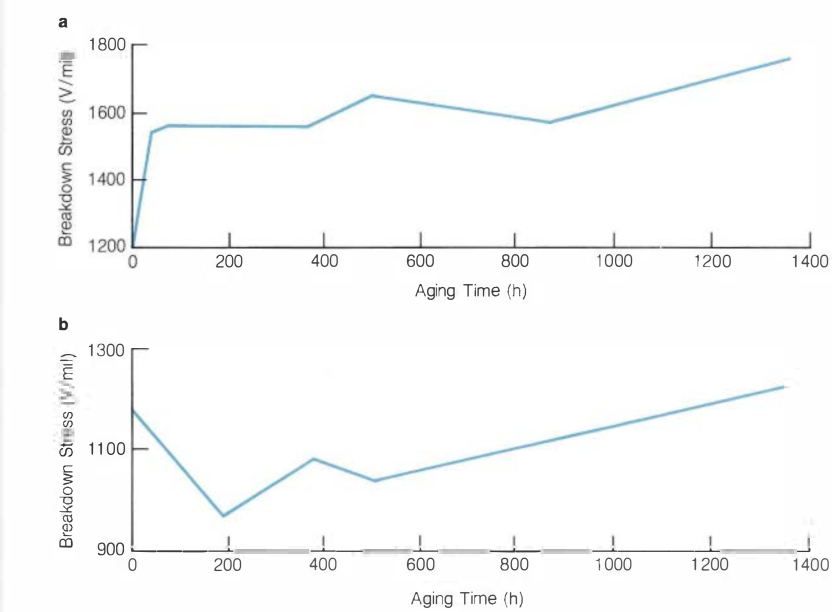


Figure 5 Probability (50%) of breakdown stress for cable insulation aged at 175°C: **(a)** XLPE cable; **(b)** EPR cable.

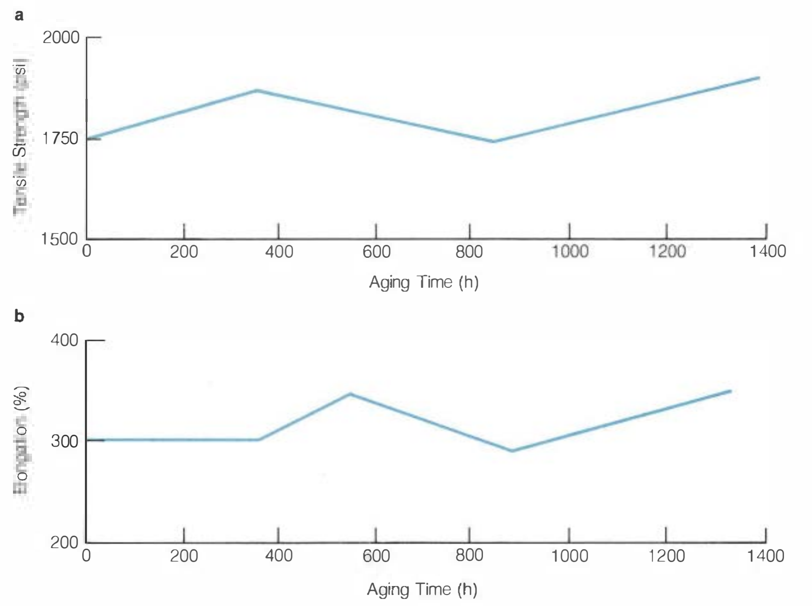
175-mil XLPE or EPR insulation, 40-mil insulation shield, and copper ribbon metallic shield; this construction was used to evaluate various thermal overload conditions. Both continuous heating and load cycling have been employed.

Figures 4a and 4b show physical properties (tensile strength and elongation) of the XLPE cable insulation oven-aged at 175°C for periods up to 1400 hours; Figures 5a and 5b show a 50% probability of 60-Hz breakdown stress for XLPE and EPR. Small specimens were removed from cable for these tests.

Figures 6a and 6b show tensile strength and elongation for EPR-insulated cables. Of interest from these data is the fact that there is no severe loss of physical or electrical properties at 175°C. Other test results indicate that problems exist in the aging of jacket materials and some of the insulation shield materials at these temperatures.

CTL will be testing cables at lower conductor temperatures, as well as cables with varied tape shield constructions. When the project is completed (late 1983), a more definitive understanding of thermal overload characteristics will have been developed. *Project Manager: Bruce S. Bernstein*

Figure 6 **(a)** Tensile strength and **(b)** elongation at breakdown of EPR insulation compared with oven-aging time at 175°C.



René Malès, Director

ACID DEPOSITION: DECISION FRAMEWORK

A decision framework has been developed to summarize current information and uncertainties about acid deposition (RP2156). The framework is intended to help decision makers assess strategies for controlling anthropogenic emissions and mitigating the effects of acid deposition. The framework is also intended to aid in the evaluation of research programs by such organizations as EPRI and the federal government, who are spending substantial funds to develop better information as a basis for future decisions.

The terms *acid rain* and *acid precipitation* are used to describe the complex chemical changes involving oxides of sulfur, oxides of nitrogen, and other compounds in the air that may lead to increased acidity in precipitation. Such increased acidity may, in turn, affect ground and surface waters and soils. A more comprehensive and accurate term is *acid deposition*, because the transfer of acid material from the atmosphere to the biosphere may occur not only in the aqueous phase (e.g., rain, snow, fog) but also as dry deposition, in which gaseous or particulate material is adsorbed by the ground, vegetation, or surface water.

As the debate on acid deposition has intensified, the need for an integrating framework for balancing the potential environmental effects with the cost of emission control has grown. Industry and government are faced with choices about whether to impose additional controls on power plants and other potential sources, take steps to mitigate the possible effects of acid deposition (e.g., liming of waterways and soils, management of fisheries, development of resistant species of biota), or wait until the relationship between emissions and ecological effects is more fully understood. The choice involves the careful balancing of very different types of risks. Acting now to reduce emissions carries the risk that large expenditures will be made with little or no beneficial effect, while waiting carries the risk that significant ecological damage will be incurred that could have been prevented by prompt action.

If the results of the extensive research programs under way in the United States, Canada, and Europe were available today, the choice might be less difficult. But unfortunately, crucial uncertainties may not be resolved for 5 to 10 years or longer. Until that time, it will not be possible to predict accurately how changes in emissions will affect the extent of ecological damage from acid deposition. Given these uncertainties, what is needed is a means of assessing options on the basis of the information available today. The decision framework developed in this research project offers such a means.

Overview

To understand the effects of alternative control strategies, it is necessary to understand how various levels of emission reduction may be related to the impacts of acid deposition. The potential changes in impact can then be weighed against the cost of achieving emission reductions. The comparison of various control strategies is complicated by several factors.

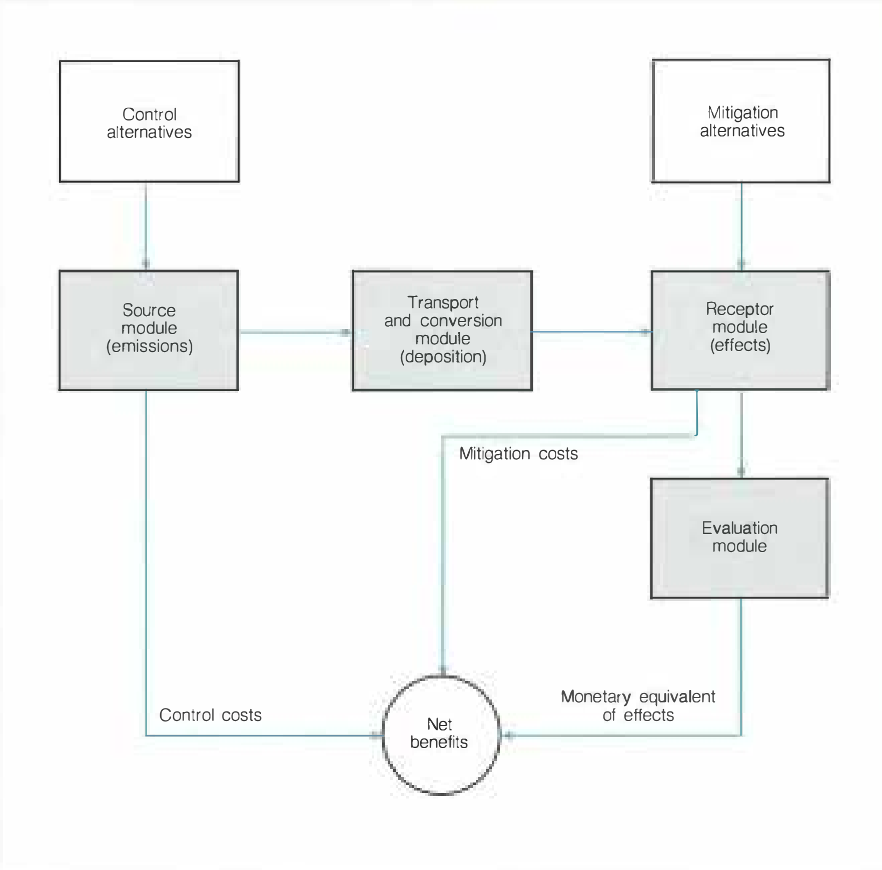
- There is a large degree of uncertainty about the relationship between emissions and effects.
- It is difficult to compare the value of changes in effects with the costs of emission reductions.
- People involved in assessing control and mitigation strategies have different degrees of uncertainty and different opinions about the evaluation of costs and effects.
- Uncertainty about the relationship between emissions and effects will only be reduced over a period of years, and the timing of this resolution is itself uncertain.

The decision framework is designed to allow explicit treatment of each of these factors, separating the evaluation of costs and effects from the consideration of the resolution of uncertainty over time. The framework provides a vehicle for the discussion and investigation of sensitive assumptions. By identifying the important areas of agreement and disagreement motivating policy decisions on acid deposition, the decision framework can assist decision makers, facilitate consensus building, and improve the quality of debate on the appropriate basis for policy decisions.

Three stages can be distinguished in the relationship between control alternatives and the effects of acid deposition. These involve the effect of control strategies on emission levels, the effect of changes in emissions on acid deposition, and the effect of changes in acid deposition on the various impacts that can be identified (possibly, for example, decreased forest productivity and the loss of sport fisheries). As shown in Figure 1, the decision framework—through its source, transport and conversion, and receptor modules—addresses each of these three stages.

There is scientific uncertainty about each stage. Relatively little is known about the third stage—that is, about how specific changes in acid deposition influence the effects. The estimates of respected scientists vary by several orders of magnitude. There is somewhat less uncertainty regarding the second stage, the relationship between changes in emissions and changes in

Figure 1 The acid deposition decision framework. The source, transport and conversion, and receptor modules determine the environmental effects of acid deposition, given a particular control and mitigation strategy. Each of these modules provides for the explicit consideration of uncertainty. The evaluation module then uses value judgments to assess how much the outcome of a particular control and mitigation strategy is worth to society. Thus the benefits of the strategy can be weighed against its costs.



deposition; the range of uncertainty is still quite large, however, owing primarily to the complex nature of the chemical transformations that occur in the atmosphere. There is comparatively little uncertainty about the first stage, the relationship between control strategies and emission levels. Accordingly, in implementing the framework, the importance of uncertainty in the second and third stages has been stressed.

The framework uses decision tree methodology to consider the available strategies and the resolution of uncertainty at different points in time. A decision tree is simply an efficient way of describing a set of scenarios. Each particular set of decisions and uncertainty outcomes makes up a scenario. Each scenario answers a "what if?" question corresponding to the choice of a particular control and mitigation strategy, followed by a particular change in deposition, in turn followed by a particular change in effects.

Figure 2 shows the time sequence of decision making and uncertainty resolution provided for in the decision tree methodology. The first two points in the diagram represent decisions within the next few years on control and mitigation options and on the funding for and direction of a national acid deposition research program. Next are two points of uncertainty resolution in the 1980s, as the research program is carried out and new scientific knowledge is obtained. One of these uncertainties involves transport and conversion (i.e., the relation of emissions to deposition), and the other involves the effects of deposition. Then comes a decision

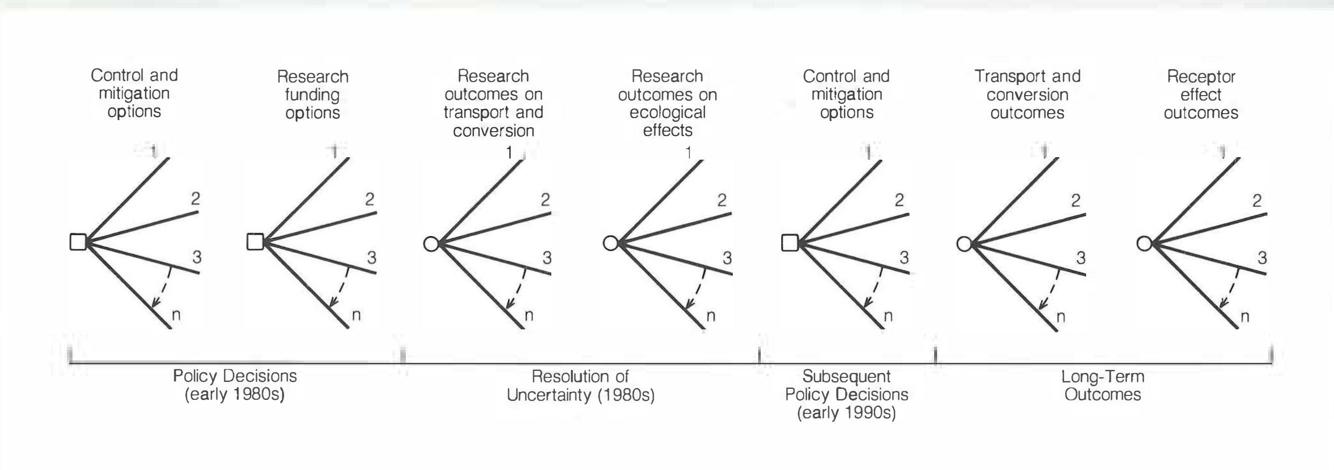


Figure 2 This decision flow diagram shows the sequence of policy decision points (squares) and uncertainty resolution points (circles) provided for in the acid deposition decision framework. A number of options or outcomes are available at each point. This structure explicitly includes the option of taking action now to control emissions or mitigate the effects of acid deposition and the option of waiting until better information becomes available in 5 to 10 years. Today's decisions on research funding and emphases may strongly affect what information does become available in the next decade, and this interaction is also explicitly considered in the methodology.

point in the late 1980s or early 1990s when national policy on control and mitigation could be reassessed and an alternative chosen on the basis of the new information available. Finally, the methodology includes two points of uncertainty resolution representing long-term research outcomes on transport and conversion and on deposition effects.

This decision tree methodology provides for a rich sequence of scenarios describing the decisions and outcomes characterizing national policy on acid deposition. It includes two stages of decision making, one with present information and one with the information that might be available in 5 to 10 years as the result of an extensive research program. The methodology explicitly includes the option of taking action now to control emissions or mitigate the effects of acid deposition and the option of waiting until better information is available. Today's decisions about research funding and research emphases may strongly affect what information becomes available in the next 5 to 10 years, and this interaction is explicitly considered in the decision tree framework.

The decision tree approach provides a useful separation between value judgments on the costs and benefits of a strategy, on the one hand, and judgments about uncertainties in the effects of acid deposition, on the other. Each decision tree scenario may be considered as having consequences on a number of concerned parties: consumers, who may have to pay more for electricity because of decisions to impose controls on power plants; fishermen and recreational property owners, who may be adversely affected if sportfishing in a given lake is degraded by acid deposition; forest product firms and property owners, who may suffer economic losses if forest productivity is reduced by acid deposition; and members of the general public concerned about possible ecological changes from acid deposition.

The evaluation of these effects is difficult because the parties involved are aware that some will bear more of the costs resulting from a particular decision, while others will receive more of the benefits. The political reality is that government officials will evaluate how trade-offs will be made between the costs that one group bears and the benefits that another group receives. Issues of equity and property rights make such value judgments extremely difficult. It is useful to separate these value judgments from uncertainties about the effects of the long-range transport of sulfur and other pollutants. The decision framework accomplishes this separation between the determination of what will happen in various control, mitigation, and uncertainty resolution scenarios and the evaluation of what each outcome is worth to society.

Implementation

The decision framework has been implemented as a computer model that represents a set of decision trees. Computerization makes computation fast and flexible and the model easy to use. Two types of decision tree are available. Both are based on the structure presented in Figure 2. The first, the basic tree, assumes that uncertainty about the relation of emissions to deposition and about the extent of ecological effects will be resolved 5 to 10 years from now. This tree can be used to quickly evaluate strategies and calculate the value of achieving full resolution of uncertainty. The second type, the research emphasis decision tree, maintains the two stages of uncertainty resolution shown in the figure—one in the 1980s and one for long-term research outcomes. While this tree is more complex, it allows the investigation of research alternatives that result in partial resolution of uncertainty. Both decision trees use the same basic assumptions and evaluations, the only difference being the extent of scientific judgment required about how uncertainty will be resolved over time.

The relationships between emissions, deposition, and effects are built up from simple modules that are easily understandable. The reduction in emissions resulting from a specific strategy is phased in over time. Various assumptions about the change in deposition that results from a change in emissions can be used. The pattern of lake and forest acidification that occurs can be varied. Each of these relationships can be changed within a wide range of possibilities, and each is modular so that it can be replaced by an entirely different set of assumptions, if desired. For example, the module that calculates the reduction in emissions could be replaced by a specific time pattern of emissions input by the user.

The use of the framework relies heavily on the assessment of judgmental probabilities. The decision tree model requires that such probabilities be provided as input data. The assessment process is a difficult and subtle art, especially in this application, where the judgments concern issues of great complexity and cut across many scientific specialities. The key to success in using judgmental probability is the credibility of the analysis process. The expert whose judgment is being assessed must understand the assessment process and the way in which his or her judgment is being used. This requirement implies that substantial time will be needed for communication between the analysts responsible for assessing probabilities and the experts whose judgments are sought.

It should be stressed that the goal of RP2156 is the development of the framework. The project has not attempted to use the model to evaluate alternative acid deposition control and mitigation strategies but has simply provided a demonstration of the decision tree model by using illustrative data. To facilitate its application in the acid deposition debates, the computer program for the decision tree model is now available to interested parties through the TEAM–UP library at Battelle, Columbus Laboratories (*EPRI Journal*, January/February 1982, p. 46) and the Electric Power Software Center. The final report for this project includes a user's guide that describes the computer code and provides instructions for setting up and running the model. *Project Manager: Richard Richels*

EVALUATION OF VISIBILITY CHANGES IN NATIONAL PARKS

The Clean Air Act Amendments of 1977 mandated that EPA develop regulations to protect scenic vistas by "the prevention of any future, and the remedying of any existing, impairment in visibility." Protected vistas are those in Class I visibility areas, which include most national parks, national wilderness areas, and national monuments. EPA is now assessing the degree of visibility impairment in Class I areas and its causes in order to take appropriate protective action. Possible steps include retrofit controls on existing power plants and additional controls on new plants to limit particulate, SO_2, and NO_x emissions. The 1977 amendments do, however, require that the costs of achieving improved visibility be considered in relation to the benefits derived. To help address this issue, EPRI initiated a project with Charles River Associates, Inc., to develop a methodology for measuring the benefits of improved visibility at Class I areas (RP1742). The methodology and its application at two national parks are described below.

Methodology

Ideally, the measure of benefits from improved visibility would be obtained from market data. The frequency and costs of visits to parks would be related to alternative visibility levels and the information used to derive estimates of the benefits of improved visibility. The assumption is that more people would visit a park and more money would be expended during periods of good visibility. Unfortunately, such market data are not available. Plans are generally made well in advance of a visit, with little or no information about the level of visibility on the day of the visit. Moreover, visibility is only one of the attractions of a park. Ruins, tranquility, foliage, recreational activities, and nearby attractions also influence park visitorship, and an analytic approach based on market data would not be able to discriminate among the impacts of a park's various attributes.

In the absence of market data, the best approach is to construct a hypothetical market and to learn how people respond to it. Two variations of this approach were used in this study, bidding game techniques and contingent ranking methodologies, with emphasis on the latter. Bidding game techniques are essentially auctions for an attribute, for example, improved visibility. These techniques have been widely used, but results can be biased, depending on the initial value given to the bidder in the auction and on whether the subject chooses to deliberately distort a bid in order to influence the outcome of the study. As a result, economists have expressed concern about the use of bidding game results.

Under the contingent ranking methodology, subjects are presented with a series of alternatives; in the case of the EPRI study, these were alternative vacation destinations (e.g., national parks). The study examined variations of certain attributes of the destinations: visibility, congestion, educational and recreational activities, and entrance fee. By determining how the ranking of alternative destinations changed with changes in these attributes, estimates of the value attached to an attribute can be made through a statistical model.

The contingent ranking methodology is based on the theory of consumer behavior and consumer preferences. This theory attempts to describe how consumers choose among similar products and to relate their choices to product attributes. A commodity's value is assumed to be dependent on its attributes and on the importance of each attribute to the consumer. By studying the trade-offs the subjects make between various attributes (here, for example, entrance fee and visibility level), it is possible to quantify the value of an attribute. Statistically, this is accomplished by estimating the set of weights for each attribute that maximizes the likelihood that a random individual will rank the alternatives as they were ranked in the study.

Case study:
Mesa Verde National Park

Two hundred subjects were asked to rank according to preference six vacation destinations, including Mesa Verde National Park in southwestern Colorado. This park was represented by eight combinations of attributes in which visibility level, entrance fee, and congestion were varied. Congestion was represented by the length of the wait to enter Balcony House, a popular ruin at the park. Four visibility levels were considered: intense plume, intense haze, moderate haze, and clear. These were represented by four slides of the same vista made from National Park Service photographs. The visual range varied from about 120 km (intense haze) to about 260 km (clear). Care was taken to ensure that the slides were similar (e.g., same lighting conditions and film batch).

The ranking mechanism involved the sorting of cards, each of which represented a combination of attributes. Each respondent's card deck included one card that represented relatively common summer conditions: an entry fee of $2 per vehicle, a one-hour wait at Balcony House, and an intense plume visibility condition. Cards representing other attribute combinations were selected by a random drawing procedure, subject to constraints so as to avoid the occurrence of combinations where one choice completely dominated another.

The survey design allowed a quantification of the trade-off between changes in visibility and in entry fee through use of a statistical procedure. The procedure estimated a set of weights for each attribute that maximized the likelihood that the ranking obtained would occur. An aggregate model was used to examine the interaction between visibility values and such population characteristics as income and age. These two factors were found to have minimal influence on the value given to improved visibility at Mesa Verde. Age did influence the value given to waiting time, however, with older subjects valuing shorter waits less than younger subjects.

There was considerable variation in response among individuals. Accordingly, the attribute parameters were estimated for each individual, summed over individuals, and averaged to yield benefit values for the various attributes. On average, visitors to Mesa Verde were willing to pay $5.10 per vehicle to have clear visibility conditions instead of an intense plume, $4.57 per vehicle for clear conditions instead of an intense haze, and $2.84 per vehicle for clear conditions instead of a moderate haze. The standard errors of estimate (1.15, 0.95, and 0.60, respectively) indicate a fairly small variation around the mean estimated values. (The negative values assigned to improved visibility were assumed to be zero in calculating the standard errors.) The value of no wait over a one-hour wait at Balcony House was $2.43 per vehicle (0.35 standard error).

To relate these results to power plant emissions, the study considered alternative emission levels for a typical western plant composed of three 700-MW (e) units. The units were assumed to burn pulverized low-sulfur, moderate-Btu, strip-mined western coal (0.7% sulfur, 8800 Btu/lb, and 22% ash). Their conversion efficiency is 34–37%, and the boilers typically operate at 50–75% of rated capacity. The boilers meet an NO_x emission level of 0.7 lb/10^6 Btu. Unit 1 achieves 99.8% particulate removal, and the other units, 97%. Although the units have limited SO_2 controls, there are no flue gas desulfurization facilities. Alternative emission levels were postulated that could be representative of best available retrofit technology (BART) controls: for particulates, 0.03 lb/10^6 Btu or 1% of emissions, whichever is stricter; for NO_x, 0.5 lb/10^6 Btu; and for SO_2, 70% removal.

Table 1 gives total suspended particulate (TSP), SO_2, and NO_x emissions for three levels of control: no controls, assumed existing controls, and postulated BART controls. For Units 2 and 3, the BART controls would probably require retrofitted baghouses with a minimum collection efficiency of 99.9%. BART SO_2 controls would involve a reagent-addition slurry and recirculation system for Unit 1, increasing its SO_2 removal efficiency from 30 to 60%. Dry scrubbers would be installed for Units 2 and 3, yielding an SO_2 removal efficiency of 75%. All three boilers would be equipped with low-excess-air, dual-register burners to reduce NO_x emissions from 0.7 to 0.5 lb/10^6 Btu. The annualized costs of these BART controls would be approximately $77–$86 million.

Data on the existing visibility conditions at Mesa Verde during the tourist season show that intense plumes occur about 11% of the daylight hours, intense haze about 19%, moderate haze about 56%, and clear conditions about 14%. Thus it was assumed that 14% of the visitors encounter clear con-

Table 1
MODEL PLANT EMISSION PARAMETERS

	Emissions (lb/10^6 Btu)			Control Efficiency (%)		
	No Controls*	Existing Controls	BART Controls	Existing	BART Incremental	BART Total
Unit 1						
TSP	20.0	0.04	0.04	99.8		99.8
SO_2	1.59	1.06	0.6	30.0	43.4	60.0
NO_x	0.7	0.7	0.5	0	28.5	28.5
Units 2 and 3						
TSP	20.0	0.6	0.0006	97.0	99.9	99.96
SO_2	1.51	1.51	0.38	0	75.0	75.0
NO_x	0.7	0.7	0.5	0	28.5	28.5

*Assumes that the ratio of fly ash to bottom ash is 80:20 and that 5% of the sulfur in the coal remains in the ash.

ditions and would not pay to achieve additional benefits. The remaining 86% would be willing to pay between $2.84 and $5.10 to obtain clear conditions. The weighted average value of improving visibility from existing levels to clear conditions is about $3.00 per vehicle.

Scenarios were developed to relate visibility levels to emission controls at a hypothetical plant (as characterized above) in the Four Corners area. One entailed a change in visibility resulting from the addition of the postulated BART controls; another entailed a hypothetical change in visibility reflecting the elimination of all emissions from the plant (the equivalent of removing the plant itself). The visual plume blight model (VIEWPB), developed by The Research Corporation of New England, was used to model the changes in emissions from the hypothetical plant and their effects on visibility. The resulting visibility condition frequencies are presented in Table 2.

The annual benefits of the scenarios were determined by weighting the average values to individuals of changes in visibility levels and multiplying by the 167,000 visitor vehicles per year at Mesa Verde National Park. Table 3 shows the results. The annual benefits of improving visibility from existing levels to clear conditions were estimated to be about $0.5 million. The benefits of the improved visibility resulting from the BART controls were estimated to be only $57,000. In addition to this method, which can be called deterministic, a probabilistic approach was used in which subjects were given frequency distributions of visibility conditions to rank instead of absolute visibility levels. As shown in the table, the difference between the results from the two approaches is not very great.

Case study: Great Smoky National Park

A similar experiment was carried out for Great Smoky National Park in Tennessee and North Carolina. In this study visibility levels were represented by varying haze conditions; no plume conditions were considered. The conditions were clear (visual range of 100 km), slight haze (50 km), moderate haze (20 km), and intense haze (10 km). The study did not consider park congestion, but it did consider visitor center activities. In contrast to the Mesa Verde results, where the value of improving visibility was minimally influenced by income, for Great Smoky the value was found to increase with the income of the visitor. This result was factored into the analysis.

The original plan was to relate changes in pollution control levels at a model power plant to reduced atmospheric loading and changes in the frequency of the four visibility conditions. However, it was determined that reducing emissions at a typical power plant in the area from existing levels to zero would increase the amount of time that clear visibility conditions occur by only about 2%. No attempt was made to evaluate this small change in visibility; instead, hypothetical scenarios were developed to test the sensitivity of visitors' values to changes in the distribution of visibility levels. Model results indicated a statistically significant increase in values only for the change from existing conditions to the most improved set of conditions considered. In this case the number of clear days about triples over existing conditions (29% versus 10%), days of intense haze almost vanish (1% versus 15%), days of moderate haze are one-third as numerous (10% versus 30%), and days of slight haze increase (50% versus 35%).

Three scenarios of increased visibility were evaluated: a change from existing conditions to the improved conditions just described, a change from these improved conditions to clear or slightly hazy conditions, and a change from existing conditions to clear or slightly hazy conditions. The clear and slight haze visibility levels were combined because it was ambiguous whether the former was preferred to the latter. The estimated benefits associated with these scenarios are as follows: from existing to improved conditions, $3.35–$5.00 per vehicle; from improved to clear or slightly hazy conditions, $4.00–$6.50 per vehicle; and from existing to clear or slightly hazy conditions, $8.50–$10.50 per vehicle. Total annual benefits can be obtained by multiplying these figures by 1 million, the number of visitor vehicles per year.

Project results

Under RP1742 the benefits of improved visibility conditions to visitors at two national parks were estimated and related to alternative emission levels at typical power plants. The benefit estimates were derived through the use of a new methodology that is based on the theory of consumer preference and that does not suffer from many of the draw-

Table 2
FREQUENCY OF VISIBILITY CONDITIONS MESA VERDE NATIONAL PARK
(% of summer daylight hours)

Visibility Condition	Existing Controls	BART Controls	No Plant
Intense plume	11	1	0
Intense haze	19	20	2
Moderate haze	56	60	60
Clear	14	19	38

Table 3
BENEFITS OF IMPROVING VISIBILITY
MESA VERDE NATIONAL PARK

Visibility Improvement Scenario	Benefits ($ million/yr) Deterministic Approach	Probabilistic Approach
From existing conditions to clear conditions	0.504	0.516
From BART control levels to clear conditions	0.448	—
From existing conditions to BART control levels	0.057	—
From no plant to clear conditions	0.301	0.155
From existing conditions to no plant	0.204	0.361

backs of earlier methods used to estimate visibility benefits.

The results indicate that the benefits of improved visibility are relatively small. The annual value of improving visibility from existing conditions to clear conditions was about $0.5 million at Mesa Verde National Park and about $10 million at Great Smoky National Park. In contrast, the costs of controlling emissions to postulated BART levels at typical 2000-MW (e) power plants in the areas around these parks are estimated to be $60–$85 million annually. Furthermore, these costs would be associated with only partial visibility improvement because other sources, including natural ones, contribute to existing visibility levels. *Technical Manager: Ronald E. Wyzga*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

ADVANCED FUEL CELL TECHNOLOGY

The major objective of EPRI's fuel cell research is to introduce first-generation phosphoric acid fuel cells with a heat rate of ~8000 Btu/kWh into utility use (EPRI Journal, *January/February 1982, pp. 49–51). These systems will function on natural gas, light-distillate hydrocarbon, or alcohol fuels. The objectives of the advanced fuel cell technology subprogram are (1) to develop electrode materials that will improve on the above heat rate and result in more robust fuel cell components in these moderate-temperature (~200°C) acid fuel cells, and (2) to explore potentially more efficient systems, such as the molten carbonate cell, which promises a heat rate of 6800 Btu/kWh (coal to ac power) when integrated with a coal gasifier in baseload power plants. Previous* Journal *articles and R&D status reports have been presented (June 1978, p. 34; November 1978, p. 6; November 1979, p. 40; and July/August 1980, p. 45).*

The EPRI advanced fuel cell technology subprogram consists of three project groups.

- Development of new materials for the oxygen cathode of phosphoric acid fuel cells, coupled with research to increase understanding of the comparatively poor performance of the oxygen electrode in phosphoric acid electrolytes (RP1200)
- Development and testing of novel organic and inorganic acid electrolytes that may result in performance improvements over phosphoric acid for the oxygen electrode reaction (RP1676)
- Development and testing of improved materials and cell structures for molten carbonate fuel cells (RP1085)

Acid fuel cell technology

Phosphoric acid was chosen during 1968–1970 as the preferred acid fuel cell electrolyte because of three important physical (not electrochemical) properties: chemical stability, allowing its use at temperatures in excess of 150°C to facilitate the electrochemical reactions (oxygen reduction and hydrogen oxidation in the presence of carbon monoxide) and to allow waste heat recovery for reforming fuel; low equilibrium water vapor pressure at the high acid concentrations under these temperature conditions; and very low volatility. For system reasons, these properties are highly desirable in a practical fuel cell electrolyte, and concentrated phosphoric acid is the only common acid combining them. It does, however, show inferior oxygen electrode performance compared with other acid electrolytes, leading to a loss of 0.1 V in cell potential. Eliminating this loss could improve fuel cell heat rate by as much as 15%.

To improve the performance of phosphoric acid cells, researchers have tried to further increase the cell operating temperatures and pressure. This, however, places more stress on electrode catalysts, supports, and construction materials. RP1200 was initiated in 1978 to determine the temperature limits for the stable performance of critical materials in the phosphoric acid fuel cell under utility operating conditions, to develop improved materials where necessary, and to attempt to determine and remove some of the causes of oxygen electrode performance loss.

In fuel cells built prior to 1977 (4.8-MW demonstrator being tested by Consolidated Edison Co. of New York), pure platinum of high surface area, dispersed on carbon black, was used as the cathode catalyst (RP842). Commercial fuel cells will operate at higher temperatures, pressures, and cell potentials than the 4.8-MW demonstrator, which would cause rapid corrosion and decay of the pure platinum and carbon black catalyst systems. In the two years since the July/August 1980 status report, a deeper understanding of the catalyst and materials problems in phosphoric acid fuel cells has been obtained (RP1200-2). Corrosion of the catalyst support has been shown to be the most important factor governing catalyst stability and lifetime under normal operating conditions. Tests are showing that the more highly corrosion-resistant supports, such as steam-treated acetylene black, appear to be sufficiently stable and durable to maintain platinum crystallites with 35–40-m^2/g surface areas, even after 40,000 hours. The implication of this result is that a plant heat rate ~8300 Btu/kWh can be maintained for at least 40,000 operating hours, and long-term confirmation testing of these data is currently under way. In addition, new techniques have been developed for producing a corrosion-resistant, graphite-type catalyst support material by catalytic heat treatment at a comparatively low temperature (1600°C instead of 2700°C). This technique should reduce electrode fabrication costs and allow preservation of the high surface area of electrocatalyst supports.

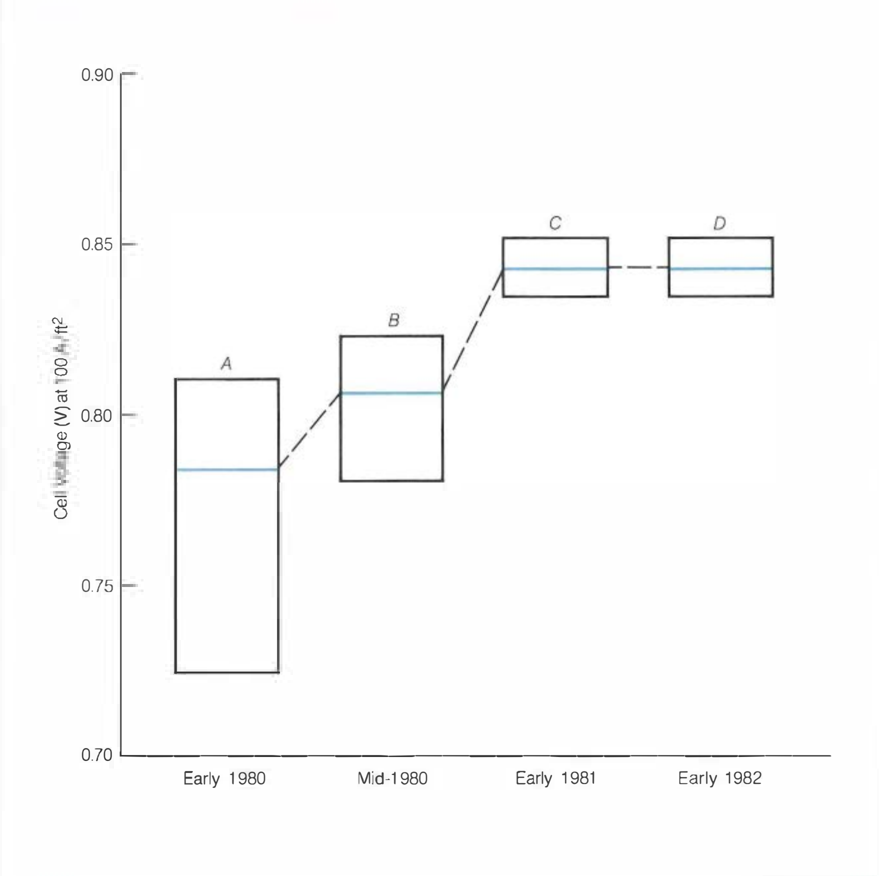
In the future, as more-efficient fuel cells are developed, involving operation at yet higher temperatures and pressures (e.g., at 0.8 V per cell, yielding a plant heat rate of 7300 Btu/kWh), catalyst supports that are more resistant than graphite may be needed. Candidate materials may include high-surface-area metallic carbides and silicides, which are currently being examined (RP1200-8).

The advanced catalysts of a type of platinum intermetallic compound (Engel-Brewer alloys, such as Pt_3V) developed under RP1200-5 are key to the attainment of high efficiency and long electrode life. Characterization and improvement of these catalyst types are continuing (RP1200-1, -2). Although their corrosion resistance and activity both appear to be greater than those of pure platinum, problems still occur in depositing reproducible batches on the advanced corrosion-resistant supports. In addition, further work is required on electrode structural optimization (e.g., Teflon content, heat-treatment temperature). When proved in practical electrodes, the new catalytic materials will also be available for use in the Westinghouse Electric–Energy Research Corp. gas-cooled utility fuel cell program, improving its performance to an 8600-Btu/kWh heat rate at 0.73 V per cell.

As the electrochemical performance of the oxygen electrode is better in acid electrolytes other than phosphoric acid, it would be highly desirable to find new acids that combine acceptable physical properties with improved electrochemical performance.

Such acids as fluorophosphonic acid (FPO_3H_2) that are themselves not physically suitable as fuel cell electrolytes are being synthesized and evaluated to help understand the characteristics of the desired acid. Some of this work has already shown promising results (RP1676-1, -2, -3). Tetrafluoroethane disulfonic acid (not previously described in the published literature) has been synthesized in several-hundred-gram quantities. Initial tests show performance at 100°C to be equivalent to phosphoric acid at 200°C under pressure. Although this acid is stable and nonvolatile, it appears to lose water and form an anhydride above 100°C, which thus represents its upper temperature limit. More work is required to arrive at a more suitable molecular structure, and attempts are being made to synthesize higher fluorinated sulfonic acids. In parallel, the adsorption of phosphate and fluorocarbon sulfonate anions on platinum is being studied to determine if this phenomenon is responsible for the poor performance of phosphoric acid for oxygen reduction (RP1200-9).

Figure 1 Development of 1-ft² molten carbonate fuel cell stacks by United Technologies Corp. The voltage spread indicates intercell dispersion from the best cell in the stack down to the poorest. The interior line (color) represents the average cell in the stack. (*A*) 20 cells; the last tile stack. (*B*) 8 cells; the first improved electrolyte stack. (*C*) 10 cells; electrolyte stack with improved anode and parts matched for assembly; 3000-hour endurance test. (*D*) 10 cells; electrolyte stack with improved separator plate and random assembly.



Molten carbonate fuel cells

Major progress has been made toward practical molten carbonate fuel cell designs and components. In 1980, laboratory cells lacked the ability to withstand thermal cycles, had excessive internal resistance, and could not sustain normal excursions of gas pressure differentials across the cell structure. These problems have been addressed, in somewhat different ways, by the three major EPRI–DOE contractors (United Technologies Corp. [UTC], General Electric Co., and Energy Research Corp [ERC]). Emphasis at UTC is on a cell design that employs a thin lithium aluminate electrolyte matrix with low internal resistance. It is used in conjunction with a composite nickel-ceramic anode structure of proprietary design that also serves as a differential-pressure barrier. These structures have now been tested in 1-ft², 10- and 20-cell stacks, in which sealing and manifold gasketing problems have been overcome (Figure 1). Recent stacks as fabricated have shown very good performance in short-duration tests (3000 hours) under pressure conditions and represent a considerable advance over the state of the art in 1980.

At ERC (RP1085-3) and at General Electric (RP1085-8) direct deposition of lithium aluminate or other ceramics onto either anode or cathode structures by electrophoretic deposition is being examined. Various techniques for impregnation of this very adherent coating with carbonate electrolyte have been developed. Electrophoretic deposition promises to be a cost-effective and high-quality method to prepare electrolyte structures.

Nickel-sinter anodes developed by ERC (RP1085-3) are similar in principle to those at UTC but different ceramic impregnation methods are used. Similar structures, again using different preparation methods, are being developed by General Electric under in-house and DOE programs.

Although lithium-doped nickel oxide electrodes produced by in situ oxidation methods give good performance and stability as air cathodes under atmospheric pressure conditions, they show some deterioration under the high-pressure (120-psi; 827-kPa) conditions required to give high efficiencies (such as the potential 6800-Btu/kWh coal-to-ac power heat rate) in utility central stations. Consequently, more-stable materials, such as perovskites and spinels, are being examined at UTC (RP1085-4) and at Ceramatec, Inc. (RP1085-6). These will be made available to other molten carbonate fuel cell contractors. For fuel anodes, the Institute of Gas Technology is investigating ceramic-stabilized, sintered-copper composites as possible lower-cost substitutes for sintered nickel (RP1085-2).

UTC has completed a study of the kinetic conditions under which carbon is deposited and methane is steam-reformed or formed from carbon monoxide and water at the anode. This study is important to define precise inlet gas composition ranges that allow highest voltage performance and utilization, especially under pressure conditions, and at the same time, avoid carbon and excessive methane formation (RP1085-4).

Studies conducted by ERC and UTC for the Gas Research Institute on molten carbonate fuel cells with internal methane reforming indicate that very simple systems with the potential to achieve 5500–6500-Btu/kWh heat rates may be possible (depending on cell potential and reactant utilization). These good heat rates result from the ability to use the fuel cell waste heat directly to supply the endothermic energy of the reforming reactor. They should show great promise as very efficient dispersed generators with cogeneration capability.

Once successfully developed, the molten carbonate fuel cell can be expected to cover a wide range of future applications, from small (perhaps as small as several hundred kW) methane- or methanol-fueled generators to coal-fired utility central stations, all with fuel-to-ac efficiencies of 50% or better. *Project Manager: John Appleby*

Figure 2 Volkswagen Type 2 Electro-Transporter used in TVA utility fleet demonstration. Five vans and five mini-buses were employed in delivery and vanpooling missions.

ELECTRIC TRANSPORTATION

In recent years petroleum supply concerns have led to renewed interest in electric vehicles (EVs) for general urban use. Both private and government-supported efforts to develop practical EVs are well under way in this country, as well as in Europe, Japan, and elsewhere. An increasing variety of EVs can be purchased commercially. EPRI is involved in testing and evaluating currently available EVs and in helping to develop key components, assess potential effects on electric utilities, and prepare for large-scale field tests and eventual mass production. The testing and evaluation of these vehicles are particularly important services to the fledgling EV industry and to its potential early customers, such as electric utilities.

An earlier status report (*EPRI Journal*, March 1981, pp. 52–55) covered the initial EPRI-sponsored testing at Southern California Edison Co. and the first efforts at the Tennessee Valley Authority. At that time, SCE had completed its vehicle tests, which led to the selection of the Volkswagen Type 2 Electro-Transporter for the TVA evaluation of electric vehicles in utility missions (Figure 2). TVA had obtained 10 of these vehicles (5 vans and 5 minibuses) and was actively using them in delivery and vanpooling missions in Chattanooga, Tennessee.

Since that time, TVA's Phase 1 vehicle testing has been completed and a more comprehensive Phase 2 effort has begun. This report summarizes the Phase 1 experience and discusses some early findings of the testing efforts in Phase 2. It also describes the testing activities planned for the remainder of Phase 2. Other related Electric Transportation Program activities, such as the testing and improvement of batteries and other components, will be covered in later reports.

The Electric Vehicle Test Facility, located on TVA's Chickamauga Dam reservation near Chattanooga, was completed during Phase 1. The construction and equipping of this facility were financed jointly by TVA, DOE, and EPRI. The facility includes a one-mile dual-banked test track and a 9600-ft^2 (892-m^2) passive-solar-heated building. The building contains vehicle maintenance bays, a chassis dynamometer, component and battery testing facilities, charging stations, computer equipment, and administrative offices. The facility's comprehensive capabilities and dedicated technical staff constitute a powerful resource for TVA and EPRI's efforts to advance EV technology.

Utility fleet uses of EVs

During Phase 1, a detailed methodology was developed for selecting utility missions appropriate for EVs. Some 15 route/mission assignments were selected and tested. Over an 18-month period nearly 54,000 mi (87,000 km) were driven, mainly in vanpooling and transfer of personnel and supplies among TVA's facilities in the Chattanooga area.

The Volkswagen vans and minibuses have 144-V propulsion batteries (twenty-four 6-V modules). Exide EV-106 grid-plate batteries were used in the vans, while Hoppecke tubular-plate batteries from West Germany were mounted in the buses. Both were of similar capacity—132 Ah (475 kC) at the 75-A discharge rate. Thus equipped, all vehicles demonstrated about a 35-mi (56-km) maximum range under real-world utility mission conditions. Actual missions of 15–30 mi (24–48 km) were used for most vehicles. After traveling an average of some 5400 mi (8700 km) per vehicle by the end of the 18-month test period, battery capacity had deteriorated to the point that range was less than 15 mi (24 km). This battery capacity loss was found to be caused mainly by production defects in the batteries and excessive overcharging. These problems may be avoided by improving battery manufacturing quality control and using the more-accurate charging control devices that are now becoming available.

When driven under similar conditions, the vans and buses had essentially the same total (ac) energy consumption per mile. As actually used during the test period, the vans averaged 0.83 kWh/mi (0.52 kWh/km) in comparison with 0.93 kWh/mi (0.58 kWh/km) for the buses. Variations in these rates were caused mainly by differences in driver skills, terrain, charging procedure and temperatures, and payload.

Average availability of the vehicles was nearly 90% of all service days. Although this is an improvement over some earlier EVs, it is still not adequate. Problems were most severe early in the test period, reflecting high "infant mortality" among various components. Although vehicles were quickly returned to service in most cases, these problems and the extensive preventive maintenance efforts undertaken thereafter caused maintenance costs to be higher than for comparable conventionally powered vehicles. Again, however, many of the difficulties appear to be avoidable with currently available vehicle, battery, and charger technology.

TVA conducted a detailed survey and analysis to estimate the number of EVs that might be used in its own vehicle fleets and those of its distributors. Limiting their study to 2-ton vehicles or smaller, the TVA researchers concluded that about 700 of TVA's 3200 vehicles of this size could be replaced by EVs with a 40-mi (64-km) range at the end of battery life. Another 200 of the vehicles used in TVA's employee vanpooling program could be replaced by EVs recharged at each end of the trip. TVA's many local distributors were estimated to operate some 2000 additional vehicles that could be replaced by EVs under similar criteria.

The utility fleet demonstration effort is continuing in Phase 2, with vehicles assigned to a broader range of missions and personnel. An extensive driver training program is being used, together with a driver log procedure to ensure continuing documentation of vehicle use and performance. An automated data collection system has also been developed to aid in such documentation.

EV state-of-the-art testing

In addition to the continued utility fleet demonstration, the Phase 2 effort at TVA includes testing and evaluation of individual EV models that represent advances in the current state of the art. EPRI's approach to this testing is based on its own experience at SCE, TVA, and elsewhere over the past five years, plus direct assistance from the Gesellschaft für Elektrischen Strassenverkehr (GES), a West German organization responsible for EV evaluation and development for that country's electric utilities.

The TVA program includes a mix of track, road, and dynamometer tests. From four to six months and 1500–2000 mi (2400–3200 km) of testing are required to complete each vehicle evaluation. The first vehicles tested were the Grumman-Olson Kubvan and the Volkswagen pickup conversion by South Coast Technology, Inc. (SCT). Both represent good examples of the EV technology available in light work vehicles potentially useful in utilities and other commercial fleets. The Kubvan is a custom aluminum unit-body minivan with a 435-lb (195-kg) payload. It has an 84-V propulsion battery and was designed for low-speed, frequent-stop service, such as postal delivery. The SCT-converted VW pickup has a 108-V system and a 760-lb (345-kg) payload, and it is intended for general urban use. Exide XPV23-3 batteries were used in these EPRI–TVA tests.

Table 1 indicates the average range and total ac energy use for the VW-SCT pickup. The variations among these figures clearly show the dramatic effect of mission characteristics on overall EV performance. They also indicate the marked improvement in range (nearly 75%) made possible by several 30-min intermediate recharge periods. This suggests that EV mission capabilities might be expanded considerably if facilities for frequent recharging could be provided at convenient points. In addition, Figure 3 indicates how the VW–SCT pickup and Kubvan compared in efficiency as indicated by dc (battery output) energy use under constant-speed test conditions. The figure also shows the substantial efficiency gain resulting from installation of a later-model controller in the Kubvan. This is an example of the rapid rate of EV component improvement now in progress.

Testing of the Ford Escort conversion by Jet Industries, Inc., is now in progress. Other vehicles to be tested in the near future include both passenger cars and trucks. Candidate vehicles for these tests include other Ford Escort conversions, the Electrek car by Unique Mobility, Inc., and several recently introduced British trucks with capacities of 2–3 tons. Separate evaluation reports will be prepared for each to assist manufacturers in product improvement, as well as to aid utilities and others contemplating EV purchases.

EV component evaluation and improvement

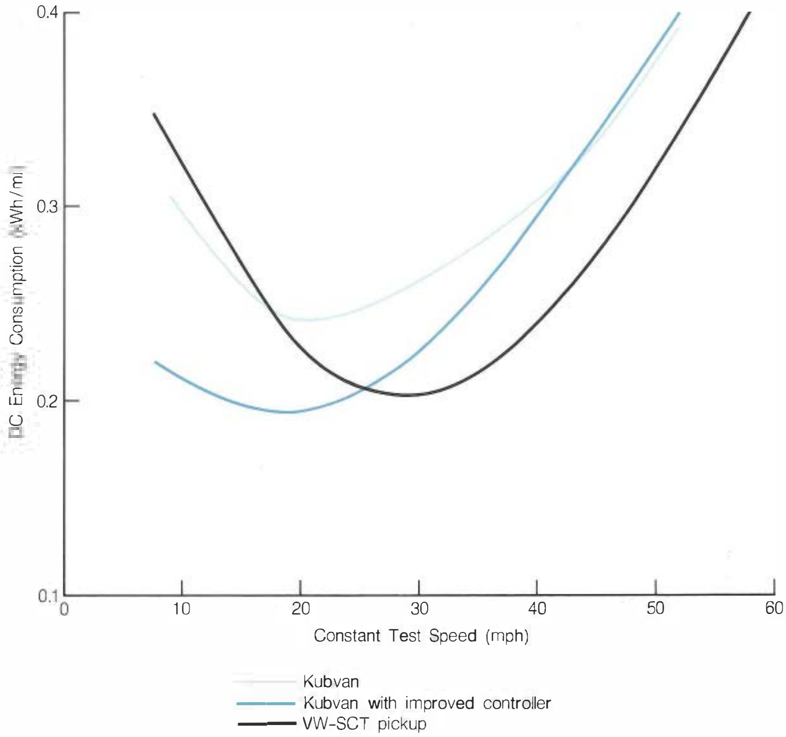
Although the focus of this report is on vehicle testing, it is inevitable that those activities lead to some useful observations and findings concerning specific components. One such example is regenerative braking. In tests on the Electro-Transporters, it was estimated that its use would result in range increases averaging about 4%.

Most component-specific findings have dealt with batteries and chargers, which have been the sources of most problems in the testing program. Battery maintenance (such as adding water, checking capacity, replacing modules, tightening cables) has proved to be time-consuming and costly; component manufacturing quality controls are sometimes inadequate; present vehicles do not have accurate gages to predict remaining range; and commonly used but

Table 1
PERFORMANCE TEST RESULTS
VW-SCT BATTERY-POWERED PICKUP TRUCK

Test Conditions	Range mi	Range km	AC Energy kWh/mi	AC Energy kWh/km
Constant speed (35 mph)	62.6	100.7	0.47	0.29
SAE J227a C Cycle (urban delivery/service)	28.5	45.9	1.06	0.66
Urban flat route	25.1	40.4	1.19	0.74
Urban flat route (with intermediate recharge)	43.9	70.6	1.02	0.63
Urban hilly route	23.2	37.3	1.27	0.79
Urban hilly route (with intermediate recharge)	29.6	47.6	1.28	0.80

Figure 3 Relationship between dc energy consumption and constant test speed for Grumman-Olson Kubvan and VW–SCT pickup, showing the initial vehicle comparison and the effect of different motor controllers on the Kubvan's energy efficiency.



faulty charging procedures and equipment can severely reduce both battery capacity and life. In addition, closer control of battery temperature has been found to be needed during both charge and discharge in order to optimize performance and avoid damage to the battery. However, it now appears that solutions to most of these problems may already be available or close at hand with innovations such as single-point battery watering, microprocessor range prediction devices, self-compensating taper chargers, battery compartment thermal management systems, and improved battery designs. All these are subjects of related EPRI testing and/or development, much of it involving TVA and the Electric Vehicle Test Facility.

Projections

The EPRI–TVA EV testing experience to date has identified both a variety of remaining problems and a steady improvement in EV technology. Test results suggest that currently available EVs can meet the requirements of a variety of missions and that frequent or intermediate recharging can extend range to make many more missions possible. At the same time, the level of specialized maintenance required by these contemporary EVs indicates that fleet rather than personal applications are most likely to be feasible for the near future. EPRI's EV testing and related R&D efforts are expanding to assist this promising technology in reaching commercial feasibility. *Project Manager: G. H. Mader*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

ARMP CODE: LWR CORE SIMULATION

As indicated by the words on which the acronym is based, the original intent of the various research projects whose output comes under the generic heading of ARMP (advanced recycle methodology program) was the generation of a unified system for LWR core simulation that would encompass plutonium recycle as well as uranium assembly designs (RP118). The general unavailability of reprocessing in this country has practically foreclosed the plutonium recycle option. Nevertheless, over 40 domestic utilities currently apply the ARMP system for the general support of LWR operations with particular emphasis on core follow; verification of the core supplier's design in general and cycle depletion characteristics in particular; fuel management independent of the core supplier. A few utilities have used the system in the course of independent licensing efforts. In addition, Brookhaven, Oak Ridge, Los Alamos, Argonne national laboratories, and other DOE laboratories utilize all or part of the ARMP code system.

The nodal and concomitant thermal-hydraulic codes for each LWR scheme in ARMP-0, released in 1977, were distinct versions tailored to pressurized and boiling water reactor systems, respectively: NODE–P and –B; THERM–P and –B. The PWR lattice and the BWR multibundle lattice codes were PDQ/HARMONY (P/H). The pin-cell code of the PWR sequence was EPRI–CELL, a unique linking of the GAM, THERMOS, and CINDER codes. The single-bundle lattice code of the BWR sequence was initially the multigroup collision probability code, CPM. About a year later, many utilities opted for the faster and easier-to-use CASMO code and for the first version of the SIMULATE code in place of EPRI–NODE–B. EPRI–CELL and its ENDF/B library were benchmarked against assorted isotopics and critical experiments. The CPM ENDF/B library, particularly the U-238, was then normalized against hot full power EPRI–CELL runs on consistent infinite lattice bases.

Semiannual meetings of the ARMP User Group have served several vital purposes related to necessary improvements, enhancements, and accretions to the ARMP codes and to the subsequent transfer of the revised technology to the utilities. (Utilities host these meetings except for one held in Palo Alto, California, every two years.) At these gatherings, EPRI contractors and personnel describe ongoing or recently completed research projects involving ARMP or related codes; utility personnel present results of the application of ARMP codes, or occasionally, the application of other code systems equivalent to ARMP. These meetings are notable for the exchange of information, both formally and informally, and the all-important feedback from utility users on problems in applying codes, as well as discussing areas for incremental development.

At present, the ARMP system is more well defined and mature in its PWR side. A draft PWR procedures manual has been available for over two years, providing step-by-step instructions for the preparation of 3-D nodal simulations and of quarter-core (XY) P/H depletion runs (RP976). A draft P/H manual, which provides substantial clarification of the venerable Bettis documents, has also been distributed (RP976). However, one deficiency (soon to be remedied by the Pseudax enhancement to P/H) has been the unavailability of a 2-D fine-mesh code with thermal-hydraulic feedback (e.g., Westinghouse Electric Corp.'s TURTLE code). In most other aspects, however, the ARMP system is tantamount to those of the PWR vendors and, perhaps, superior in lumped-absorber treatment.

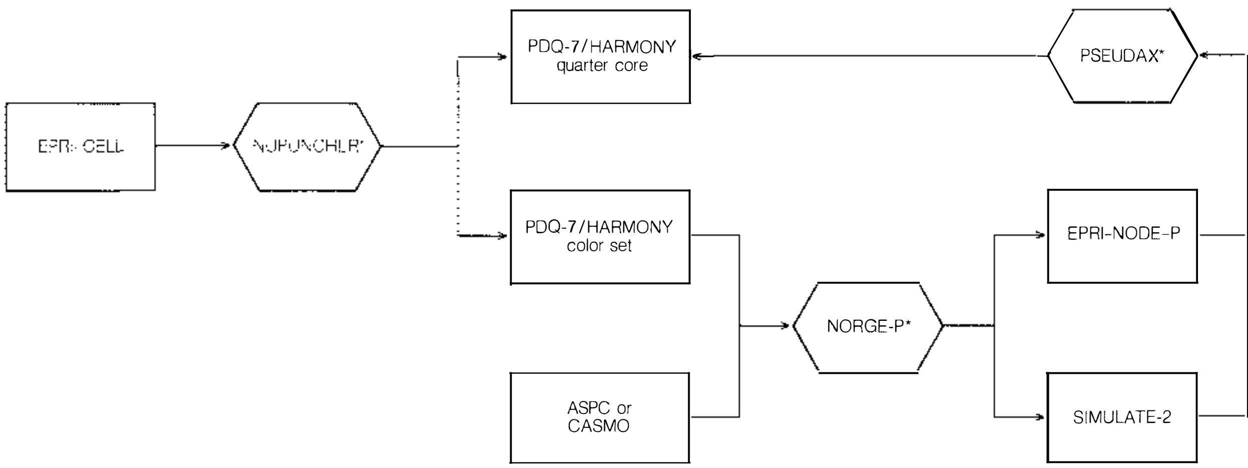
The development of the BWR side has lagged somewhat because the coupled nuclear and thermal-hydraulic processes that the nodal code must model are substantially more complex than those for PWRs. With the imminent availability of SIMULATE-2, with extensions of existing codes to allow calculations at cold conditions (as well as margin calculations), and with improved thermal-hydraulics integrated into the nodal solution, the upgrading of the BWR sequence to parity with that for PWRs can be seriously anticipated.

This year ARMP-0, together with VIPRE-1 and RETRAN-02, will be formally subsumed into the reactor analysis support package (RASP-01). The ensuing paragraphs describe ARMP-1; the modifications distinguishing this version from the extant ARMP-0 have either been completed or correspond to the output of research projects that will be complete by the end of 1983.

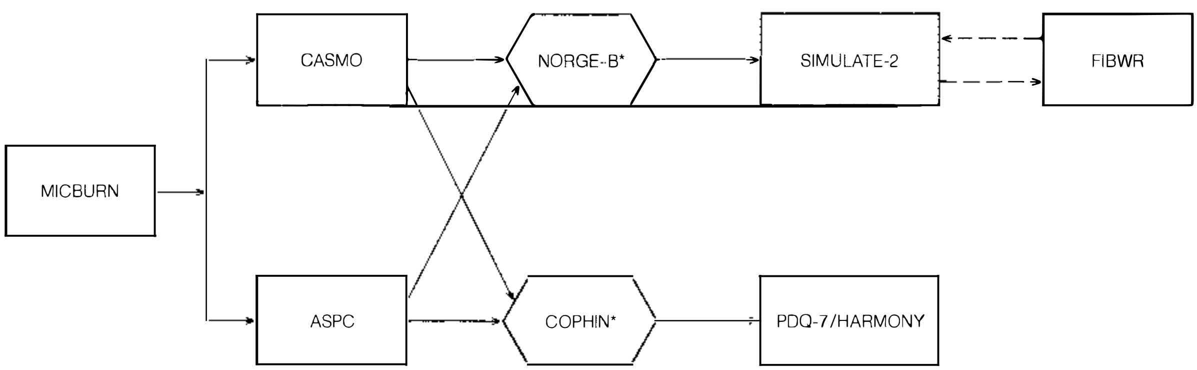
Figure 1 schematically summarizes the interrelationship of the major PWR codes; in Figures 1 and 2, processing codes that link the output of one physics module to the input of another are indicated by asterisks. Virtually every code module shown in Figure 1 will be new or will have been substantially revised from the initial releases. EPRI–CELL has already been the object of programming, physics, and engineering-modifications (RP1252). The PDQ-7/HARMONY (P/H) code has undergone such extensive modifications under EPRI projects that to satisfy the strictures of naval reactors, EPRI has become a secondary distributor of the code (RP1690).

In a PWR, assembly-averaged power, either axially averaged or edited at a particular axial location, can show significant shifts between hot zero power (HZP) and hot full power (HFP) conditions. Cores as disparate in age as Ginna Core-1 and Comanche Peak-1 show at least 15% net power shifts (defined as the sum of the reduction of the

Figure 1 ARMP-1: Specific components of PWR sequence.



*Processing code linking the output of one module to the input of another module.



*Processing code linking the output of one module to the input of another module.

Figure 2 ARMP-1: Specific components of BWR sequence.

peak assembly power plus the increase in the lowest assembly power in going from HZP to HFP). The original version of P/H as incorporated in the ARMP system did not account for the moderator density and resonance temperature feedbacks that are responsible for these net power shifts. To remedy this and provide other capabilities, the Pseudax methodology has been developed, involving changes to EPRI–CELL, NUPUNCHER, both PWR nodal codes, and principally, to P/H (RP1709). The changes to the two nodal codes, EPRI–NODE–P and SIMULATE, have been the inclusion of HARMONY format edits for assembly-averaged power from each axial plane of the XYZ solution. Besides power (implicitly the resonance temperature), these edits include the local water density. This information is then presented to P/H as input. Through a succession of fixed-source runs, P/H then produces a fine-mesh power and flux distribution, which on the assembly average, matches the specified input power. Optionally one may perform pinwise resonance temperature (Doppler) calculations within each assembly about the externally imposed average value.

ASPC is a development of CPM that will be faster than CPM for comparable problems, will be easier to use, and will incorporate several improvements (RP1252).

NORGE–P is a flexible data processing code that will accept the output of ASPC, CASMO, or P/H color sets (the adjacent quadrants of four assemblies that are differentiated by enrichment and burnable poison complement, each unique combination being a color). For use in this path, the P/H output files have been altered from machine language (RP976).

SIMULATE-2 designates a significantly improved version of the SIMULATE nodal code, which was released by EPRI in 1978 (RP710). The SIMULATE code is notable for the several neutronic options it contains: flare-type, coarse-mesh diffusion theory (CMDT), modified CMDT (or PRESTO-type model). The new version adjusts radial edge leakage corrections, depending on the migration length of the outermost nodes. It accommodates different "A" factors for rodded and unrodded nodes. It will be faster running than the original release and incorporates other significant user-oriented improvements, as well as the new EPRI void model.

Similarly, EPRI NODE–P will be substantially improved over the original release version. The improvements will be primarily in the area of basic programming efficiency, as a spin-off from the PWR/PSMS effort sponsored by EPRI. One significant methodology change will be an optional three-moderator temperature history capability. This option will be added in connection with the code linking NODE–P to RETRAN, called NODETRAN.

The draft PWR procedures manual will be upgraded to include those accretions to the methodology made since the issuance of the original draft. The formal version of this PWR manual will be issued along with upgraded and new code manuals, as necessary.

Figure 2 summarizes the interrelationship of the major BWR codes. MICBURN is a special code, auxiliary to ASPC and CASMO, which treats a gadolinia-loaded fuel pin in some geometric detail within the pellet. Multigroup macroscopic cross sections for the gadolinia and appropriate fissile and fission product cross sections are edited and then input to the respective assembly analysis codes.

NORGE–B is a processing code similar in function to NORGE–P (RP976). NORGE-B will differ from the extant NORGE code not only in the link to NODE–B but also in its extension to modeling both rodded and unrodded cold BWR configurations (68–200°F, 20–93°C). In conjunction with this methodological extension to cold conditions, a simple perturbation theory approach will be implemented in SIMULATE-2 to estimate the worth of control rods.

The COPHIN code processes the depletion-dependent output of the indicated assembly analysis codes into input for P/H. It was originally generated to allow the representation with depletion of more than one BWR assembly.

The dashed lines in Figure 2 between FIBWR and SIMULATE-2 represent a two-level linking of FIBWR methodology into SIMULATE-2.

A draft BWR procedures manual will be released (RP976). This manual will serve as a guide to the various code manuals used in the BWR sequence and will provide background information and procedures for effective modeling of the core. This manual will serve as a suggested starting point for BWR analysts. With utility feedback, it is expected that it will develop into a formal document analogous to its PWR counterpart. *Project Manager: W. J. Eich*

PROBABILISTIC RISK ASSESSMENT

A comprehensive probabilistic risk assessment (PRA) has been undertaken by the Nuclear Safety Analysis Center (NSAC) and Duke Power Co. on Duke's Oconee Unit 3. The effort includes participation by six other utilities to gain experience in state-of-the-art PRA methods and their application. The analysis is specific to the Oconee plant and site; however, the approach and methods chosen and the experience gained will be available to all nuclear plant owners and operators at a time when PRA methods are assuming an increasingly important role as an aid to regulatory, safety, and operating decisions.

The value of additional realistic studies of commercial nuclear plant accident sequences was pointed out by many of the government and industry reviews of the TMI-2 accident. At the same time, PRA methodology was gaining momentum as a valuable tool for making safety and licensing decisions. In early 1980 NSAC initiated a project with Duke to perform a PRA on its Oconee Unit 3 (RPR103).

In line with the principal objective of improving the industry's ability to use PRA methods as a working tool, volunteer participants from six other utilities were included on the project team; representatives from three contractor organizations (Technology for Energy Corp.; Science Applications, Inc.; and Pickard, Lowe and Garrick, Inc.) were retained to provide methodology expertise; and the involvement of several contractor organizations was sought in order to expose the project team to diverse points of view on the methods and applications. The Institute of Nuclear Power Operations (INPO) is providing support and expertise in the area of human reliability analysis, and NSAC is managing the project.

The project scope includes identification of important initiating events (failures of plant equipment and failures from external causes); modeling those plant equipment failures that could lead to loss of reactor core cooling; analysis of physical processes and radionuclide transport within the containment building; and calculating atmospheric dispersion and dose consequences of radionuclides released from containment. Each facet of the analysis was to be done by using models and data specific to Oconee Unit 3. The project was not intended to develop new methodology, but it was intended to consider current alternative methodologies and select a combination that was best suited to the project objectives and staff.

In accomplishing this scope of work, the utility personnel on the project team were to be exposed to the various facets and methodologies of the project and gain direct hands-on experience in at least two of the major facets. Particular attention was paid to the modeling and quantification of human errors that could contribute to loss of core cooling and accounting for dependencies between plant systems and equipment, including treatment of such events as seismic, fire, and flood. Sources of uncertainty in the analysis were identified, and where practical, quantified. On completion of the project, a working model representing the important ingredients of the analysis will be turned over to Duke for its future use in evaluating safety issues or potential plant modifications. The initial scope of the project had included an evaluation of the financial risk of plant damage from accidents; however, early work indicated that this objective was overly ambitious, and it was decided to delete it from the scope.

Progress and status

Work on the project began in September 1980, with the technical work originally scheduled for completion in late 1981 and publication of the final report scheduled for 1982. The project team was initially located at Duke's headquarters in Charlotte, North Carolina. By the end of 1980 a preliminary analysis of the initiating events and plant had been conducted. Methodology alternatives had been thoroughly discussed, and a choice of method and implementation plan had been reached for each of the major tasks. By mid-1981 the basic modeling and analysis of plant response to initiating events had been completed, resulting in a network of interconnecting event trees, top-supporting logic, and system fault trees. Generic component and human reliability data had been applied to the models, and they were being debugged in preparation for solution and quantification to identify important event sequences. The post-core-melt containment physical processes had been described in a containment event tree, and analysis of the key processes and phenomena by the MARCH computer program had been completed. Site-specific meteorology, demography, and evacuation data had been prepared for use in atmospheric dispersion and consequence analysis by the CRACIT computer program.

At that point, the emphasis on methodology comparison and training was reduced, and priority was shifted toward faster progress in completing the remaining scope. A seven-man team from the original project mounted an intensive effort during the last quarter of 1981 at EPRI in Palo Alto, California, to iterate and integrate the results. After the first solution and quantification of the core-melt event sequences, it was determined that the existing event sequence and system models carried too much detail to allow an easy solution with probability discrimination, to identify the important sequences, and to provide traceable results. It was decided that the models should be revised to collect some of the detail into modules and thus streamline the solution process and improve the accuracy and confidence of the results.

The necessary model revisions were completed by December 1981, and the models were solved a second time for the important sequences and their frequencies. At the present time, the important core-melt event sequences have been identified, potential recovery actions considered and factored in, and sequence frequency values have been finalized. These results have been input to the containment event tree model and the magnitude and frequency of radionuclide releases have been estimated. The release frequency and magnitude were then used with the previously prepared site characteristics to calculate the public health consequences off-site.

The sequences and frequency for core melt are believed to be a realistic or best-estimate characterization. However, the magnitudes of the radionuclide release and some aspects of the off-site consequence calculations are known to be overestimates because of the more limited state of technology in those areas. With the recent emphasis on degraded core technology, it is expected that a more realistic characterization of the radionuclide release for various types of reactor accidents will soon be available and will allow a more realistic estimate of public health consequences in these situations.

The final project report, some 2000 pages in several volumes, has been drafted and is currently being reviewed by EPRI and Duke. Review comments will be incorporated and the report is expected to be published by the end of 1982.

Initial results, conclusions, and experience

Some general results, conclusions, and experiences in three broad areas can be described at this time. The final results on the frequency of core melt and public health risk are yet to be published; however, the mean frequency of core-melt is dominated by the contribution of flooding incidents that could possibly result from failure in the plant condenser circulating-water system and flooding of the turbine building. The contribution from the "more traditional" initiating events (e.g., pipe breaks, transients) is about 10% of the total. The preliminary estimates of public health risk for Oconee appear to be comparable to or less than those reported by the *Reactor Safety Study* (WASH-1400).

Throughout the study a number of perceived plant or system weaknesses were pointed out for evaluation by Duke. In some cases, dialogue with the plant and technical staff showed the perception to be incorrect. In other cases, a decision on hardware modification or operating procedure was straightforward and taken quickly. A few items are still being evaluated because their importance and optimal resolution are less clear.

On a more macroscopic scale, the primary contributions to core-melt frequency and risk were tied to several salient plant features.

- The location of equipment for several front line and support systems required for core cooling is in the basement of the turbine building, where it would be disabled by a large flood.
- The seismic capacity of a number of nonstructural walls and some other equipment is such that combinations that can defeat core cooling have a relatively high conditional frequency for seismic accelerations in the range of 0.1–2.5 g.
- The requirements for operator decision and action in several important event sequences are in relatively short timeframes.
- Support systems can impact necessary core-cooling functions by disabling multiple front line systems.

Important strengths in the Oconee plant were also found. The capacity of the reactor containment building is adequate to withstand all but the most rare and severe effects of a core-melt accident. The sources of electrical power are so numerous and diverse that electric power failures did not contribute significantly to the core-melt frequency.

In addition to the analysis results, a number of important results about PRA methods and process were also derived from the study. A PRA study of this magnitude is a very arduous undertaking, and the best possible effort must be made before the start of work to define the job in specific detail. Frequent replanning is required, but good planning and control is vital. Another important lesson from the Oconee PRA is that the addition of new analysts to a project team should be limited in order to provide adequate day-to-day guidance and to maintain direction and progress. Project technical direction will require one or more individuals who have experience in all phases of the PRA process. Access to accurate plant design and operating information is essential; if the plant is operating or nearly so, a qualified plant operator should be assigned as a full-time member of the project team.

Much was learned about the state of the art in PRA methods during the course of the project. The final conclusion is that it is rapidly evolving. The usefulness of any PRA project results will depend more on the skill of the analysts and their understanding of the plant and its operation than on the style with which they approach the problem. The approach ultimately selected for the Oconee PRA relied heavily on methodology from the *Reactor Safety Study* and adaptations made since then by other studies. Some innovations were made in the way event trees and fault trees were linked and solved to form event sequence; the extent to which human errors were modeled and quantified; and the extent to which initiating events, secondary systems, and support systems were linked into the plant sequence/system models. A number of other approaches are being studied or used (for example, the GO methodology described in the *EPRI Journal*, July/August 1982, p. 55).

Overall, the Oconee PRA experience demonstrates that PRA methods are an excellent tool for examining the whole plant, penetrating system interfaces, structuring the thought process on how failures can occur, and keeping track of equipment combinations that represent success and failure under given circumstances. The results can be a valuable aid to decision making, not only for nuclear safety issues related to public risk but also for issues relating to prudent, reliable plant operation. *Project Manager: William R. Sugnet*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1195-8	Downwell Pump Reliability	6 months	50.1	Radian Corp. *E. Hughes*
RP2048-3	Acid Corrosion in the Clean Gas Saturator of a Coal Gasification–Combined-Cycle Power Plant	1 year	61.6	Ohio State University Research Foundation *W. Bakker*
Coal Combustion Systems				
RP718-5	Alternative Fuel Firing in an Atmospheric Fluidized-Bed Combustion Boiler	7 months	195.0	Northern States Power Co. *C. Aulisio*
RP911-3	Long-Term Effects of High Temperature and Cyclic Operation on Fossil Fuel Power Plant Components	1 year	99.8	Failure Analysis Associates *T. McCloskey*
RP1645-6	Analysis of Stag Plant Coal-Fired Operation via Pressurized Fluidized-Bed Combustion Retrofit	10 months	99.8	General Electric Co. *S. Drenker*
RP1649-1	Demonstration of Acoustic Resonator	7 months	64.3	Hoover, Keith & Bruce, Inc. *A. Armor*
RP1867-4	Evaluation of 10-MW High-Sulfur Coal Fabric Filter Pilot Plant	29 months	654.9	Southern Research Institute *R. Carr*
Electrical Systems				
RP1763-2	Improved Motors for Utility Applications	45 months	846.0	General Electric Co. *D. Sharma*
RP1779-1	Detection of Electric Meter Tampering	20 months	32.1	Honeywell, Inc. *H. Songster*
Energy Analysis and Environment				
RP1487-13	Identification of Environmental Settings and Disposal Systems in the Utility Industry	7 months	39.6	Envirosphere Co. *I. Murarka*
RP1538-2	Cogeneration System Design Model	1 year	342.0	Mathtech *L. Williams*
RP1630-24	Western Regional Air Quality Studies, Gas Measurements	6 months	115.3	University of Michigan *P. Mueller*
RP1920-1	Incorporating Financial Constraints in Capacity Planning Models: Developing Improved Methodology for Estimating Financial Constraints	6 months	68.1	Charles River Associates, Inc. *S. Chapel*
RP1954-2	Population Exposure to SO_2 and Particulate Risk Estimates	10 months	99.1	H. Daniel Roth Associates *R. Wyzga*
RP2145-2	Estimating Air Conditioner Hourly Loads	6 months	36.7	Energy & Resource Consultants, Inc. *S. Braithwait*
Energy Management and Utilization				
RP1201-25	Impulse Resistance Sintering of Metal Powders With the Homopolar Generator	8 months	46.5	University of Texas *I. Harry*
RP2034-3	Reference Manual on Infiltration and Indoor Air Quality	7 months	39.6	Lawrence Berkeley Laboratory *A. Lannus*
Nuclear Power				
RP1238-3	Brittle-Ductile Transition in Ferritic Steels	6 months	29.0	Materials Research and Computer Simulation *D. Norris*
RP1324-6	Pipe Whip Test and Analysis	21 months	25.0	Tennessee Valley Authority *H. Tang*
RP1543-9	Development of Revised Design Limits for Piping	9 months	135.9	EDS Nuclear, Inc. *R. Nickell*
RP1557-9	Segregation of Uncontaminated Dry Active Waste	9 months	44.5	National Nuclear Corp. *M. Naughton*
RP1761-17	SIMTRAN 2 Development	6 months	45.0	Energy, Inc. *L. Agee*
RP1935-1	Field Wear Measurements of Cobalt Alloys	9 months	75.0	Battelle, Columbus Laboratories *C. Wood*
RP2058-6	Stress Corrosion Cracking in Small-Diameter BWR Piping	6 months	34.0	Failure Analysis Associates *M. Fox*
RP2117-2	Modeling of Removal of Radionuclides by Water Pools Under Severe Accident Conditions	7 months	69.4	Science Applications, Inc. *R. Oehlberg*
RP2169-1	A Study of Common Cause Failures	10 months	147.8	Los Alamos Technical Associates *D. Worledge*
RP2180-3	Pressure Vessel Integrity	3 months	1061.4	Combustion Engineering, Inc. *D. Norris*
R&D Staff				
RP2261-1	Reducing High-Temperature Oxidation and Scale Spallation by Salt Deposits	1 year	36.0	Lawrence Berkeley Laboratory *J. Stringer*

New Technical Reports

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

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

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

ADVANCED POWER SYSTEMS

Effect of Gasifier Feed Rate Variations on Coal Gas Combustion Characteristics

AP-2216 Final Report (RP985-1); $13.50

This project evaluated the performance of a combustor for low-heating-value coal gas and a combustor for medium-heating-value coal gas. The testing involved a series of steady-state gasifier runs in which the gasifier feed rate was varied over a 2:1 turndown ratio. The contractors are United Technologies Corp., Pratt & Whitney Aircraft, and Texaco, Inc. *EPRI Project Manager: L. C. Angello*

Design and Fabrication of a 1-MW (th) Ceramic-Tube Bench-Model Solar Receiver

AP-2398-SY Summary Report (RP475-2); $9.00

This report describes the design and fabrication of a 1-MW (th) bench-model solar receiver to demonstrate and further develop the ceramic-tube central receiver concept. An investigation undertaken to confirm the choice of silicon carbide against available metals and other ceramic materials is discussed. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Manager: J. E. Bigger*

Wind Turbine Performance Assessment

AP-2456 Interim Report (RP1996-1); $13.50

Updated information, current as of late spring 1981, is presented for federally and privately funded U.S. wind turbine R&D programs and for key European programs. The report contains detailed test results on the four DOE 200-kW MOD-0A horizontal-axis wind turbines interconnected with various U.S. electric utilities; reviews progress on the three MOD-2 2.5-MW wind turbines, the 2-MW MOD-1 turbine, and other planned installations; and presents test data and plans for the DOE vertical-axis program. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: F. R. Goodman, Jr.*

COAL COMBUSTION SYSTEMS

Failure Cause Analysis: Condenser and Associated Systems

CS-2378 Final Report (RP1689-2); Vol. 1, $19.50; Vol. 2, $22.50

Utilities were surveyed to determine how problems with condensers and associated systems affect power plant availability and performance. Volume 1 of this report discusses the data collected (from 415 power plant units) on condensers, steam systems, and circulating-water systems and presents conclusions and recommendations. Volume 2 presents appendixes of detailed data on various components and problems. The study concluded that there is a need for definitive industry guidelines for condensers and intakes. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: I. A. Diaz-Tous*

Technology Assessment: Municipal Solid Waste as a Utility Fuel

CS-2409 Final Report (RP1255-3); $22.50

The developmental status and conceptual design and economics of the following refuse-to-electricity technologies were assessed: mass burning of municipal solid waste in a dedicated boiler; preparation of coarse refuse-derived fuel (RDF) and firing in a dedicated boiler; preparation of wet RDF and firing in a dedicated boiler; preparation of fluff RDF and cofiring with coal in a utility boiler; and preparation of dust RDF and cofiring with coal in a utility boiler. This work was cosponsored by the New York State Energy Research & Development Authority. The contractor is Ebasco Services, Inc. *EPRI Project Manager: C. R. McGowin*

Development of Guidelines for Optimum Baghouse Fluid Dynamic System Design

CS-2427 Final Report (RP1129-5); $19.50

A modeling program was conducted to develop design guidelines for optimizing the fluid mechanic performance of baghouses. This report describes the formulation of modeling techniques for analyzing gas flow through the collector system; the analysis of fabric filter duct system design; and the evaluation of geometric configurations and operating conditions to establish optimal system characteristics, identify the current level of sophistication in fluid mechanic design, and develop improved designs. The contractor is Dynatech R/D Co. *EPRI Project Manager: R. C. Carr*

Universal Pressure Boiler for Cycling Operation

CS-2438 Final Report (RP1266-13); $10.50

This report describes an investigation to identify boiler system modifications that will allow existing once-through steam generators to satisfy utility system cycling requirements. To determine operational problems and equipment limitations, a series of cycling field tests were conducted on an oil-fired, subcritical, once-through boiler designed for baseload operation. The project also entailed preliminary design studies aimed at improving boiler system cycling performance. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: J. P. Dimmer*

Materials Problems in FBC and Coal Gasification Systems: Corrosion Chemistry in Low-Oxygen Activity Atmospheres

CS-2452 Final Report (RP979-6); $16.50

This report describes additional studies on corrosion chemistry in low-oxygen activity atmospheres similar to those expected in fluidized-bed combustion (FBC) and gasification systems. High-temperature materials degradation processes are reviewed, and results are presented from tests on a range of commercial and model alloys exposed for up to 2000 hours in characteristic gasification system atmospheres. The contractor is Lockheed Missiles & Space Co., Inc., Palo Alto Research Laboratory. *EPRI Project Manager: John Stringer*

Biofouling Control Assessment: Preliminary Data Base Analysis

CS-2469 Final Report (TPS80-739); $19.50

This report reviews existing data sources, identifies utility biofouling problems, classifies the problems according to general plant physical and environmental factors, and identifies areas of insufficient data and understanding. Chlorine rates, injection times, and daily injection quantities are related to various plant and cooling-water source characteristics. An annotated bibliography on biofouling and its control technologies is included. The contractor is Lockheed Ocean Science Laboratories. *EPRI Project Manager: Winston Chow*

ELECTRICAL SYSTEMS

High-Impedance Fault Detection Using Third Harmonic Current

EL-2430 Final Report (RP1285-2); $10.50

A project to develop a device for detecting high-impedance faults is summarized. Two prototypes were developed and were used to identify a variety of staged, high-impedance faults. The behavior of the third harmonic current was extensively examined for both faulted and nonfaulted systems. The contractor is Hughes Aircraft Co. *EPRI Project Manager: H. J. Songster*

Transient Efficiencies in Electric Power Plants

EL-2439 Final Report (RP1048-2); $18.00

A detailed digital computer model of a typical power plant was developed and used to investigate the impact of regulation duty on plant thermal efficiency. The model covers the dynamics of combustion, heat transfer, fluid flow, and energy storage. This report describes model development and presents the results of simulation runs. For the power plant studied, no appreciable cost could be assigned to degraded thermal efficiency. The contractor is Power Technologies, Inc. *EPRI Project Manager: C. J. Frank*

Compaction of Amorphous Ferromagnetic Metal Powders

EL-2449 Final Report (RP7876-13); $7.50

This report describes a project to determine what mechanical and magnetic properties amorphous ferromagnetic powders would retain after either explosive or isostatic compaction. Explosive (unlike isostatic) compaction appears to be successful, resulting in good mechanical bonding, the retention of magnetic properties, and a relative density of up to 91%. The contractor is SRI International. *EPRI Project Manager: Mario Rabinowitz*

Improved Economic Dispatch of Power Systems

EL-2461 Final Report (RP1048-3); Vol. 1, $15.00; Vol. 2, $34.50

This report documents an investigation of the feasibility (from the generating-unit standpoint) of updating economic dispatch system input/output curves. The effort included a survey to determine the current state of the art in economic dispatch; tests to identify boiler, turbine, and generator parameters that most influence total and incremental cost curves; and work to identify thermal, mechanical, and electrical parameters that limit the economic operation of generating units. Volume 1 summarizes the results, and Volume 2 presents appendixes of detailed data. The contractor is Philadelphia Electric Co. *EPRI Project Manager: C. J. Frank*

ENERGY ANALYSIS AND ENVIRONMENT

Sulfate Regional Experiment: Documentation of SURE Sampling Sites

EA-1902 Supplemental Report (RP862-2); $12.00

This report provides detailed information that supplements the discussion of SURE site locations in EPRI Final Report EA-1901. Air quality measurements performed at the ground stations are reported, and the deployment and specific locations of the 56 stations are described. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: G. R. Hilst*

Case Studies Using the COGEN2 Model

EA-2414 Final Report (RP942-1); $16.50

This report presents an assessment of COGEN2—a design, costing, and economic optimization model that can be used for the site-specific analysis of a proposed or existing cogeneration system. The model was applied to case studies from five utilities to test its capabilities against the actual requirements of utility decision makers and to determine if it was sufficiently useful to warrant the additional investment. The contractor is Mathtech, Inc. *EPRI Project Manager: L. J. Williams*

Radiation Protection Training Programs in Nuclear Power Plants

EA-2420-SR Special Report; $10.50

This exploratory study examined current radiation training programs at a sample of utilities operating nuclear reactors and evaluated employee information on radiation health. Through utility visits, surveys, and employee interviews, the study addressed employee perceptions and understanding of ionizing radiation; the background, training, and problems of utility trainers; the content, materials, and conduct of training programs; and program uniformity and completeness. *EPRI Project Managers: L. A. Sagan and Walter Weyzen*

Verifying Usefulness of Engineering Process Models Applied to Forecasting

EA-2441 Final Report (RP867-1); $15.00

This report describes a study that explored the theoretical validity of statistical methods developed to link engineering process models with economic forecasting models. Classical economic production theory and recent efforts to use statistical output from process models in forecasting applications are reviewed. An alternative application of functions known as cubic splines is discussed, as well as an error-minimizing nonstatistical technique that uses convex properties of the process models. The contractor is the Purdue Research Foundation. *EPRI Project Manager: A. N. Halter*

Evaluation of the ORNL Residential Energy Use Model

EA-2442 Interim Report (RP1484); $15.00

The architecture, empirical foundation, and applications of the Oak Ridge National Laboratory residential energy use model are evaluated. The strengths and shortcomings of the model in various uses are identified, along with areas where model structure and empirical support could be upgraded. Suggestions are made for improving model logic, strengthening the empirical basis for behavioral and technical parameters, and reducing the biases in the model that arise from aggregation. The contractor is the Massachusetts Institute of Technology. *EPRI Project Manager: Richard Richels*

Reliability of Electricity Supply During Oil Import interruptions

EA-2464 Final Report (RP1153-3); $19.50

This report examines the effects of oil import interruptions on the cost and reliability of service in the electric utility industry. It details (1) alternative national policies for allocating scarce oil supplies among electric utility regions during an emergency, and (2) utility industry strategies involving inventory policy and interregional electricity exchange. The results show that short-term oil disruptions could cause significant economic losses to electricity consumers if no mitigation actions are implemented during the emergency period. The contractor is Southwest Energy Associates, Inc. *EPRI Project Manager: H. P. Chao*

ENERGY MANAGEMENT AND UTILIZATION

Compressed-Air Energy Storage Preliminary Design and Site Development Program in an Aquifer

EM-2351 Final Report, Vol. 1 (RP1081-3); $13.50

This volume presents an executive summary of a study to assess the benefits of a compressed-air energy storage (CAES) facility using an aquifer as the storage medium. Three system expansion scenarios are analyzed, and the production and capital costs of a CAES facility are compared with those of other generating options. The results indicate that CAES has technical, economical, and licensing viability for near-term application in the utility industry. The contractors are Public Service Co. of Indiana, Inc.; Sargent & Lundy Engineers; and Westinghouse Electric Corp. *EPRI Project Manager: R. B. Schainker*

Zinc Electrodeposition and Dendritic Growth From Zinc Halide Electrolytes

EM-2393 Final Report (RP1198-3); $28.50

This report presents the results of a study of dendritic growth during zinc electrodeposition from aqueous zinc halide electrolytes. Theoretical models of zinc electrodeposition and dendritic growth were developed and calculations of dendritic growth rates under various model conditions were made. The contractors are Case Western Reserve University and the Illinois Institute of Technology. *EPRI Project Managers: J. R. Birk and D. L. Douglas*

Increased Efficiency of Hydroelectric Power

EM-2407 Final Report (RP1745-1); $16.50

This report presents the results of a project that examined the potential for increasing hydroelectric generation efficiency at existing plants. The physical factors studied include the uprating of turbines and generators, leakage control, and the use of flashboards. The study concluded that excluding pumped storage, there is a potential for a 17% increase in capacity and approximately a 5% increase in energy from existing conventional plants. The contractor is Shawinigan Engineering Corp. *EPRI Project Manager: Antonio Ferreira*

Identifying Prospective Users of Fuel Cell Power Plants

EM-2480 Final Report (RP1677-5); $10.50

This report describes two market screening studies sponsored by EPRI and the Fuel Cell Users Group to identify potential electric utility users of fuel cell power plants. Utility situations to which the plants might be beneficially applied were defined, and specific utilities whose circumstances appeared to reflect such situations were identified. Regional meetings were held to inform the potential utility users about the plants and to solicit utility support. The contractor is Burns & McDonnell Engineering Co. *EPRI Project Manager: D. M. Rigney*

NUCLEAR POWER

BWR Low-Flow Bundle Uncovery Test and Analysis

NP-1781 Interim Report (RP495-1); $19.50

A series of separate-effects tests was performed to evaluate bundle heat transfer and thermal-hydraulic flow conditions in a simulated BWR/6 core during a boiloff scenario. The tests were run in a two-loop test apparatus; both system pressure and power effects were investigated. The resultant thermal-hydraulic quantities (i.e., axial void distributions, two-phase levels, and heat transfer coefficients) are compared with predictions made by current thermal-hydraulic analysis methods. The contractor is General Electric Co. *EPRI Project Manager: S. P. Kalra*

Data Systems Quantitative Techniques

NP-2366 Final Report (RP1391-5); $40.50

This report summarizes analyses and decision processes developed to process data like those in the Generating Availability Data System into analytically related files through a detailed sort-search routine. The report also describes operation on these files to produce information sets that support an extensive assembly of independent analytic routines. Methods of data analysis that complement utility decision processes are presented in the form of software specifications. The contractor is The S. M. Stoller Corp. *EPRI Project Manager: J. M. Huzdovich*

Investigation of Axial Void Propagation Velocity Profiles in BWR Fuel Bundles

NP-2401 Interim Report (RP1384-2); $9.00

This report describes a method of measuring axial void propagation velocity in the core of an operating BWR. Experimental data obtained from the noise signals of a local power range monitor and traveling in-core probe detectors are compared with calculated steam velocity and kinematic wave velocity profiles. The contractor is the University of Washington. *EPRI Project Manager: L. J. Agee*

Improvements in EPRI–CELL Methods and Benchmarking of the ENDF/B–V Cross-Section Library

NP-2416 Interim Report (RP975-3); $7.50

Modifications to the lattice physics code EPRI–CELL are documented, and subsequent benchmarking of the new ENDF/B–V EPRI–CELL cross-section library for UO_2 lattices is described. To provide further verification of the EPRI–CELL methods, Monte Carlo results are presented for three numerical benchmark problems. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: Odelli Ozer*

Extended-Life Operation of LWRs: Economic and Technological Review

NP-2418 Final Report (RP1253-6); Vol. 1, $7.50; Vol. 2, $21.00

A generic review was conducted to determine the economic and technical aspects associated with the operation of nuclear power plants beyond their nominal licensed term. Volume 1 summarizes the findings and presents the conclusions. It discusses economics (worth and cost), technology, and regulation and requalification. Volume 2 contains appendixes documenting (1) studies performed to develop a basic economic model to evaluate the extended-life option, and (2) technical assessments of the major LWR replacement and refurbishment options. The contractor is International Energy Associates, Ltd. *EPRI Project Manager: M. E. Lapides*

WAMCUT–II: Fault Tree Evaluation Program

NP-2421 Interim Report (RP1233-1); $9.00

WAMCUT-II is a new computer code in the WAM family. It finds the minimal cut sets for the top event of a fault tree by using a top-down algorithm. The code restructures the tree to optimize the Boolean equation. It also removes independent subtrees and solves them separately. The contractor is Science Applications, Inc. *EPRI Project Manager: D. H. Worledge*

Stress-Intensity Factors for Surface Cracks in Pipes: Computer Code for Evaluation by Use of Influence Functions

NP-2425 Final Report (RP1757-8); $12.00

A user-oriented computer program for the evaluation of stress-intensity factors for pipe cracks is presented; the program is applicable in linear elastic fracture mechanics analysis. Stress-intensity factors for semielliptical, complete circumferential, and long longitudinal cracks can be obtained with this program. A user's manual, the source code listing, and background information are included. The contractor is Science Applications, Inc. *EPRI Project Manager: D. M. Norris*

IGSCC Surveillance System Feasibility

NP-2426 Final Report (RPT101-2); $10.50

This report presents a review of techniques designed to monitor and evaluate intergranular stress corrosion cracking (IGSCC) of high-temperature piping by using ultrasonic methods. Candidate instrumentation systems were tested on a pipe placed in a suitable environment and strained to simulate service loads. The system recommended for implementation is described. The contractor is Amdata Systems, Inc. *EPRI Project Manager: M. E. Lapides*

Irradiated Nuclear Pressure Vessel Steel Data Base

NP-2428 Topical Report (RP1240-1); $60.00

This report presents the EPRI reactor surveillance program data base (covering 50 reactor units and 73 surveillance programs) in a hard-copy, loose-leaf format; it is intended to serve as a convenient reference on the properties and embrittlement of reactor vessels. Information is presented on the chemistry of the surveillance materials, irradiation conditions, and material property results. All data are summarized in tabular form, and impact data are presented graphically. The contractors are Fracture Control Corp. and Materials Research and Computer Simulation. *EPRI Project Manager: T. U. Marston*

Procedure for Assessing the Integrity of Nuclear Pressure Vessels and Piping Containing Defects

NP-2431 Final Report (RP1237-2); $13.50

This design manual provides a simple and conservative engineering flaw assessment procedure that is applicable to the ductile materials used in nuclear pressure boundary components. Background details, information on method validation, sample problems, and methods for the analysis of work-hardening materials are included. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. M. Norris*

Dynamic Fracture and Depressurization in Pipes

NP-2440 Annual Report (RP231-1); $13.50

This report presents the results of this year's efforts in an analytic investigation of crack initiation, propagation, and arrest and the related coupled fluid depressurization behavior in pressurized piping components. It describes predictive models for the initiation and rapid propagation of ductile axial and circumferential cracks and the associated depressurization response in pipes. The contractor is the University of Washington. *EPRI Project Manager: H. T. Tang*

Workshop Proceedings: 1982 ASME–EPRI Radwaste Workshop

NP-2450 Proceedings (RP1557-5); $13.50

This report presents the proceedings of the fourth ASME–EPRI radwaste workshop, held in February 1982 in Augusta, Georgia. Topics discussed were radwaste minimization, process options, and the regulatory impact. A description of two new EPRI-sponsored projects is included. The contractor is BVC Consultants, Inc. *EPRI Project Manager: M. D. Naughton*

Steam Generator Dose Rates on Westinghouse Pressurized Water Reactors

NP-2453 Interim Report (RP825-2); $9.00

An effort to compile data on radiation fields in the steam generator channel heads of Westinghouse PWRs is described, along with a modest assessment of the influence of a few selected design and operational factors on the buildup of these fields. The report presents (1) steam generator radiation field trends for both individual and group PWRs, and (2) comparisons based on hot leg and cold leg sides, the number of steam generators at a plant, loop isolation valves, coolant flow rate, power history, and deliberate oxidation after shutdown. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. A. Shaw*

Effects of Nitrogen and Cold Work on the Sensitization of Austenitic Stainless Steels

NP-2457 Final Report (RP1574-1); $7.50

This report describes investigations of how the sensitization of unstabilized austenitic stainless steels is affected by nitrogen and molybdenum additions and by cold work. Details on various steel compositions, cold work before sensitization, the presence and effects of martensite, and sensitization conditions are reported. The contractor is General Electric Co. *EPRI Project Manager: M. J. Fox*

INFORMATION SERVICES

Research Results and Applications

RA-2349-SR Special Report; $10.00

This report represents 35 examples of EPRI research project results that have been beneficially adopted by electric utilities. It also describes 106 new near-term research accomplishments that are ready for utility application. These examples cover the entire spectrum of electric power R&D: fuel processing; power generation; transmission and distribution; energy storage and management; energy analysis; and environmental assessment and control. *EPRI Program Manager: W. H. Seden*

R&D STAFF

Proceedings of the Second Conference on Advanced Materials for Alternative-Fuel-Capable Heat Engines

RD-2369-SR Proceedings; $60.00

This report documents the second EPRI–DOE conference addressing the problems that may be encountered by structural materials in heat engine systems burning alternative fuels. The conference was held in Monterey, California, in August 1981. The topics discussed were alternative fuels, alternative fuels combustion, heat engines and heat recovery, heat engine combustion zone materials problems, airfoil cooling, ceramic coatings and monolithic ceramics, and metallic alloys. *EPRI Project Manager: John Stringer*

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