Modular Generation

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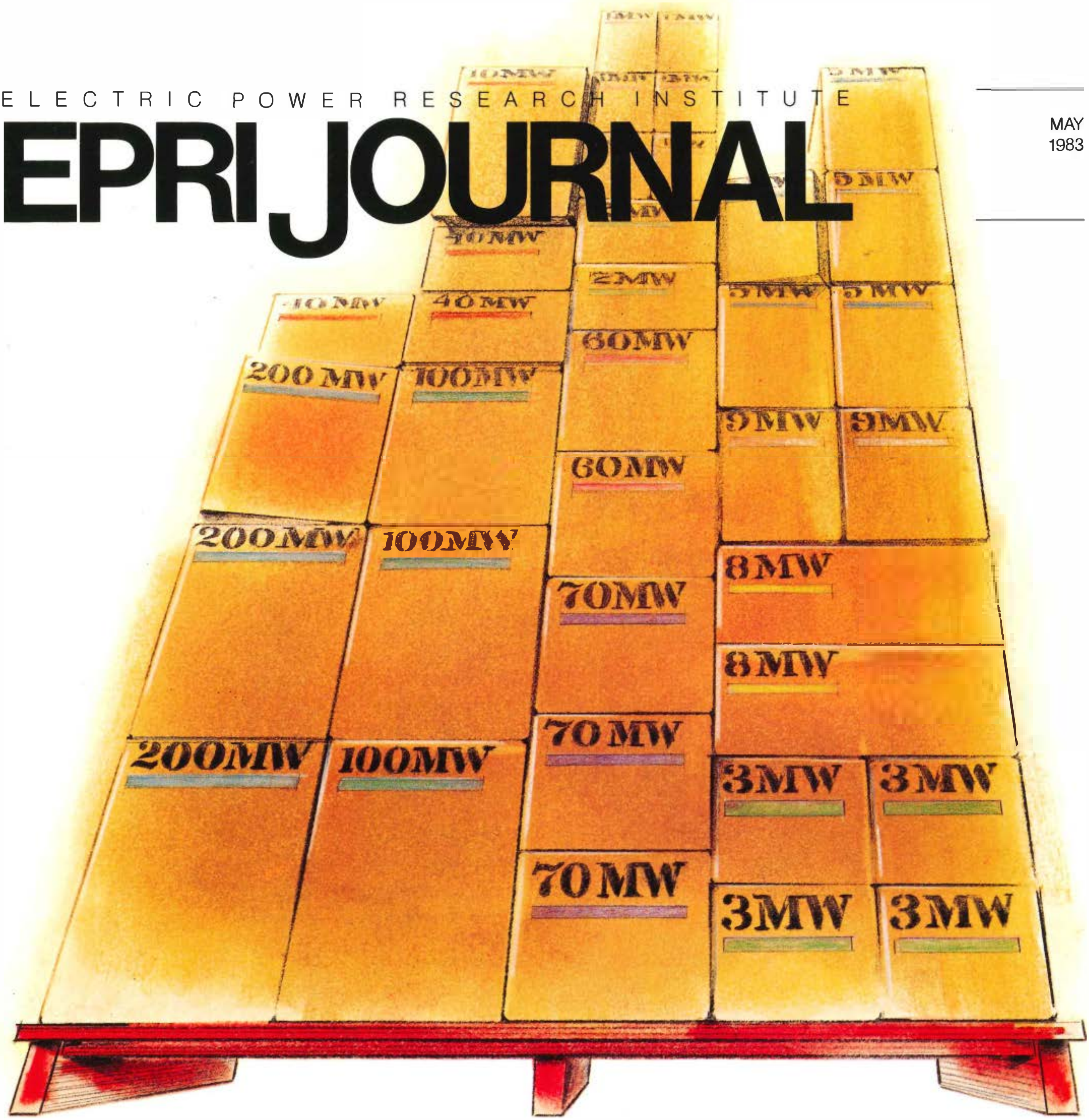

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Cover: The addition of generating capacity in small, discrete packages could become an attractive option for many utilities.

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The Promise of Modular Generation

At a time when so many electric power utilities face an unsettling present and an uncertain future, any generation technology that promises to give them more flexibility in trying to cope is welcome indeed. This month's cover story describes more than a half dozen such technologies. At first glance they appear to be only distantly related, as different as wind turbines and turbocharged boilers. Yet what they have in common is vital—the potential to enter utility service in relatively small increments quickly and efficiently, with minimum difficulty.

Interest in this ad hoc family of modular generation technologies has been particularly heightened by the recent turmoil in the American economy, as reflected in the forces affecting fuel supply, the cost of capital, and the outlook for electricity demand growth. Shorter lead times and smaller units allow utilities to cope with demand growth uncertainty by postponing critical decisions until the need for expansion is more clear. Likewise, financing difficulties have created growing interest in options that ease cash flow requirements prior to startup. Building smaller generation units in shorter time provides an excellent way to achieve such results.

Modular technologies have other advantages as well. In many cases their major components can be manufactured very efficiently in a factory and assembled more quickly in the field. This makes generators more deliverable by reducing the need to transport and custom-fabricate massive pieces of equipment at a construction site. Once installed, modular generators can also help improve overall system reliability. Removal of a small unit from service causes little disruption on the grid, and the simultaneous failure of two small units is much less likely than the failure of a single large unit with the same generating capacity. By increasing the proportion of power that comes from modular plants, utilities may thus be able to lower their reserve margins.

In the article that follows, some of the modular generation technologies EPRI believes to be most promising are discussed. Some of these, including gas turbines, combined cycles, and diesels, are already available. Fuel cells are on the threshold of commercialization. The problem is that these require fluid fuels, which are subject to uncertainties in price and supply. Our immediate aim is thus to increase the efficiency and flexibility of currently available modular technologies so as to take best advantage of valuable natural gas resources and to phase in more synfuels as they become available.

For the future, our strategy is to develop new modular generation options that can more easily use America's abundant coal and renewable energy resources. Geothermal, wind turbines, and low-head hydro look increasingly attractive in locations where adequate resources exist. Fluidized-bed combustion and gasification–combined-cycle systems can use coal in conformance with today's environmental requirements, while offering shorter lead times and inherent advantages in availability. Eventually, solar cells could offer perhaps the ultimate in deployment flexibility. The present challenge is to improve efficiencies and reduce capital costs enough to make these attractive options competitive.

Smaller, modular generation alone is not a solution to meet the needs of an increasingly electrified society. New large, efficient baseload generation relying on our extensive coal and uranium resource base will continue to play an essential role. We must persevere in refining the technology and remedying the institutional barriers that have driven plant costs to unnecessarily high levels. But even success in these efforts will not lessen the importance of the modular technologies under development. The utility industry and its needs are sufficiently diverse so that each of these options will be in demand as we strive to optimize our generating mix in the years ahead.

R E Balzhiser

Richard E. Balzhiser, Vice President
Research and Development Group

Authors and Articles

Modular generating capacity is different from simply small, and it is more than merely incremental. Moreover, it is emerging from the R&D process in various forms, reviewed in this month's lead article, **New Capacity in Smaller Packages** (page 6), by science writer Mary Wayne. Modular power options are under development in several EPRI programs, so Wayne's research took her to many people, but mainly to Seymour Alpert, Steven Drenker, Arnold Fickett, and Stanley Vejtasa.

Alpert has been technical director for the Advanced Power Systems Division for most of his nine years with EPRI. His special interests are processes and systems for the production and use of synthetic fuels. Alpert was with SRI International and Chem Systems, Inc., early in the 1970s, and from 1955 to 1970 he worked for Hydrocarbon Research, Inc., becoming research manager in refining heavy petroleum feedstocks.

Drenker, a project manager in the Coal Combustion Systems Division since August 1978, has principal responsibility for R&D in pressurized fluidized-bed combustion. Drenker came to EPRI after five years with Babcock & Wilcox Co., where he was a field service engineer for the startup of utility power plants and industrial process steam systems. He has a BS in mechanical engineering from the University of Missouri and an MBA from the University of Santa Clara.

Fickett is director of the Advanced Conversion and Storage Department in the Energy Management and Utilization Division. He came to the post in 1981 after seven years of principal responsibility for EPRI's fuel cell R&D management. Before 1974 Fickett was with General Electric Co. for 18 years, involved in fuel cell and other electrochemical developments. Between 1970 and 1974 he was manager of engineering for General Electric's direct energy conversion programs.

Vejtasa has specialized in technology evaluation for the Planning and Evaluation Division since 1981. He came to EPRI in March 1976 as a project manager for process evaluation and cost research in the Advanced Power Systems Division. Vejtasa was with Shell Development Co. from 1969 to 1976, working successively in petrochemical process engineering and in the development and testing of emission control devices. A University of Minnesota graduate in chemical engineering, Vejtasa earned MS and PhD degrees at the University of Illinois.

■

Crisis response is not the usual pace or purpose of an R&D organization, but when the TMI accident brought the reliability of relief and safety valves into question, EPRI responded quickly by accelerating its valve test activities. **Valve Test Program: Response to TMI** (page 14), by senior feature writer Nadine Lihach, discusses the special program managed successively by John Carey and Warren Bilanin of EPRI's Nuclear Power Division.

Carey, now a senior program manager for Nuclear Safety Analysis Center studies of degraded core cooling, has been with EPRI since March 1976. He managed the PWR safety and relief valve test program from its inception in 1979 until October 1981. Carey was with Argonne National Laboratory from 1968 to 1976, engaged in research on fast reactor fuel rod performance and safety tests. He attended Illinois Institute of Technology, earning a BS in mechanical engineering and an MS and a PhD in mechanics.

Warren Bilanin, who guided the valve test program from October 1981 to its completion in 1982, now manages EPRI research and associate technology transfer efforts for the Steam Generator Project Office. He came to the Nuclear Power Division in October 1979 after seven years with General Electric Co., where he developed load specifications to deal with accident-induced hydrodynamic forces in BWR containments. Bilanin has a BS in mechanical engineering and an MS in engineering, both from Northrop Institute of Technology.

Three other men were closely associated with direction of the PWR valve test work: Russell Youngdahl, corporate planning vice president of Consumers Power Co. and then chairman of EPRI's Research Advisory Committee; David Hoffman, Big Rock Point plant superintendent for Consumers Power, who chaired a subcommittee of EPRI's Safety and Analysis Department advisory task force; and James Scott, principal staff engineer in the Nuclear Assurance and Regulation Department of Public Service Electric and Gas Co., who chaired the technical advisory group of the valve test program.

■

Whenever there is not enough water available for a conventional cooling system at a new power plant, the price of water does not matter. But its value becomes very specific, pegged by the extra costs—space, structure, operation, and plant performance—of a dry-cooling system that depends on ambient air as a heat sink. **Cooling Without Water** (page 18) describes how those extra costs may be held in check by an EPRI-sponsored development that features ammonia phase change as the heat exchange mechanism.

John Bartz and John Maulbetsch contributed their expertise to this article, the first by the *Journal*'s new feature writer, Taylor Moore. Bartz, holding principal responsibility for R&D in heat rejection processes and equipment, came to EPRI's Coal Combustion Systems Division in July 1978 after 3 years with the Linde Division of Union Carbide Corp. While there he investigated an ammonia-based cooling cycle. Bartz was previously with Calspan Corp. for 13 years, engaged for much of that time in fluid mechanics research. He has a BS in mechanical engineering from the State University of New York at Buffalo and an MS in the same field from Ohio State University.

John Maulbetsch has managed the Heat, Waste, and Water Management Program in EPRI's Coal Combustion Systems Division since 1976, a year after coming to EPRI. Previously, he was with Dynatech Corp. for seven years, becoming director of the energy technology center of a Dynatech subsidiary. Still earlier, Maulbetsch was on the faculty of the Massachusetts Institute of Technology, where he had earned BS, MS, and PhD degrees in mechanical engineering.

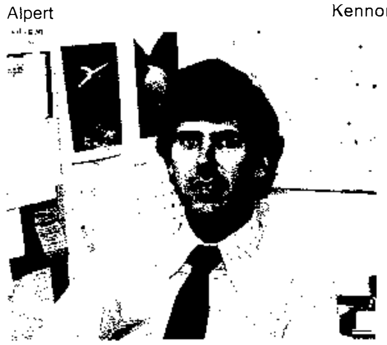
■

Perhaps the most widely applicable R&D result is a handbook—one convenient reference that organizes new information and presents the steps for applying it in the endless variety of real-life situations. Transmission line designers now have at least four more such books than they did when EPRI began. **Handbooks for Overhead Lines** (page 26), by science writer Adrienne Harris Cordova, introduces them and summarizes a few examples of their early use by utilities.

Richard Kennon was the guiding force in preparation of the article as he was of the handbooks. An EPRI staff member since February 1975, Kennon has managed the Overhead Transmission Lines Program since 1978. Previously, he worked for Westinghouse Electric Corp. for nearly 23 years, first in sales and marketing, then in engineering, becoming manager of capacitor equipment engineering in 1970. Kennon has a BS in electrical engineering from California Institute of Technology and an MBA from Indiana University.

Alpert

Kennon



Drenker

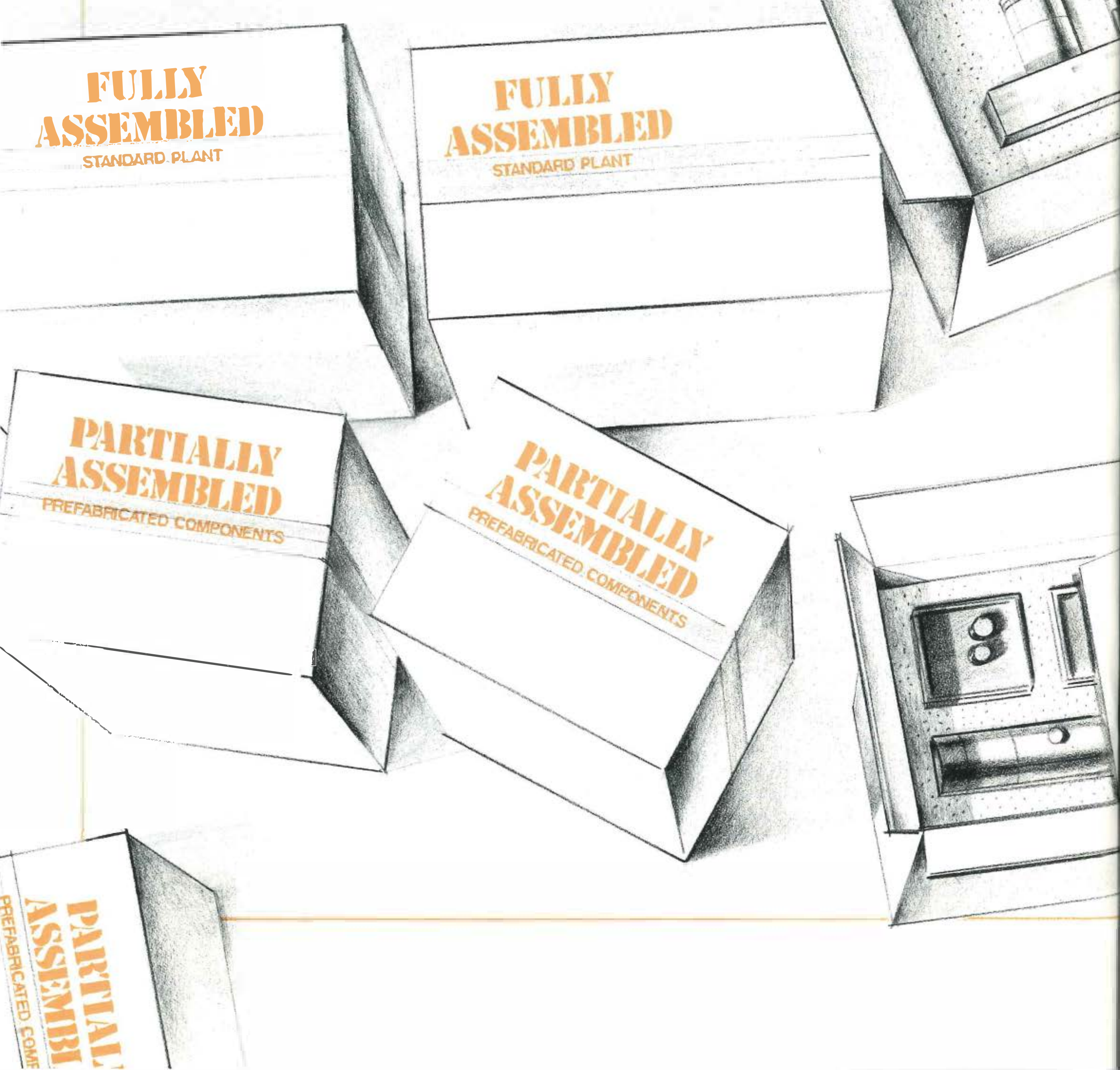
Fickett

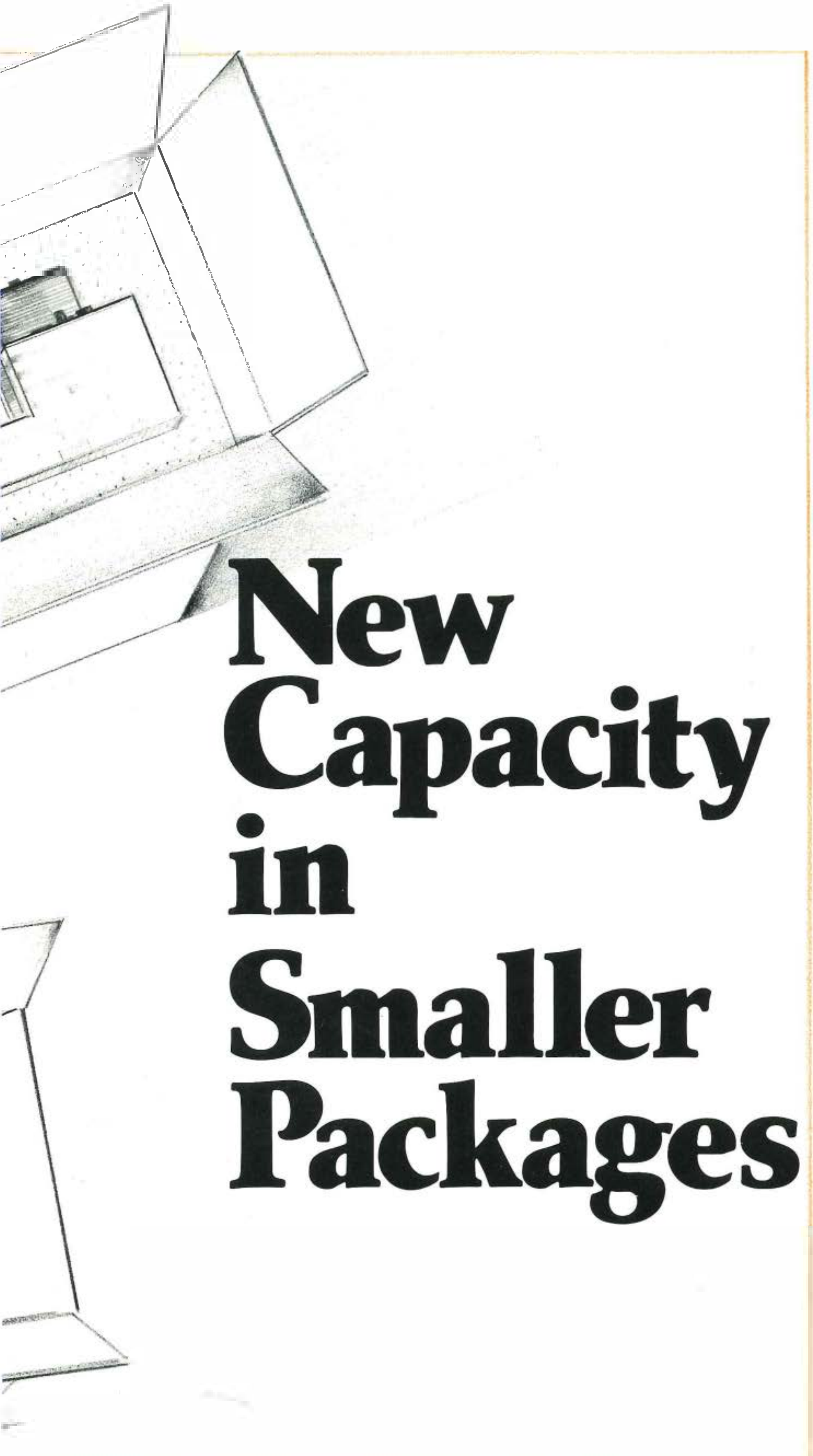
Bartz Maulbetsch

Carey Bilanin

Vejtasa

The ability to add capacity in small, prefabricated modules would give utilities greater flexibility in facing the problems of load growth uncertainty and capital scarcity. A new generation of modular technologies, ranging from wind turbines to fuel cells, could offer such flexibility in the 1990s.





New Capacity in Smaller Packages

Bigger has been better in the utility industry for many years. Economies of scale have greatly reduced the real costs of power production. But changing conditions are now prompting many utilities to take a fresh look at the matter of generating-unit size.

Uncertain load growth, constricted cash flow, and long lead times for large units define a new operating climate. It is risky to commit scarce capital to build a large unit that must be started many years in advance of the anticipated need. What if that need fails to develop, or develops several years later than expected, leaving the utility with excess capacity on its hands?

Today's financial climate requires a sharp match between capacity and demand because a major mismatch in either direction carries substantial costs. Building system capacity in small steps may be one way to optimize that match—hence, the growing interest among utilities in the concept of modular generation.

What is modular generation?

Modular generation may be characterized as the use of discrete packages of generating capacity that can be replicated and added to existing utility systems. So far, the modular approach is more a potential than a reality. The motivating forces—demand uncertainty and financial problems—may change. Much also depends on the successful demonstration and commercialization of technologies that are still under development.

Using small-capacity increments may help control a utility system's financial risk, but smallness has carried a traditional penalty: relatively high unit ($/kW) capital costs. The modular approach to going small tries to reduce and compensate for this penalty by streamlining the process of capacity addition. Modular packages would be in the size range of 250 MW or less—small enough for many of the components to be built in the factory instead of in the field.

Factory fabrication could furnish a number of advantages. A factory's highly trained, home-based labor force is substantially more productive than a comparable workforce in the field. The three work shifts at a factory mean faster production. A controlled factory environment could eliminate the impact of bad weather on production time and allow more thorough quality monitoring. The nation's advanced waterway system could provide barge transport of factory-produced components, or even fully assembled modules, to many power plant sites. Rail or truck transport could also be used in some cases. The sites themselves would be spared much of the disruption that field fabrication activities may involve. Experience in the petroleum and petrochemical industries has already confirmed the benefits of factory fabrication.

With prefabricated components, on-site construction time for a power module would be reduced considerably. Overall lead times for modular additions, including design, licensing, and construction, could be 7 years or substantially less, in contrast with the 8–14 years typically required to bring larger units on-line. And the favorable environmental characteristics inherent in many of the modular technologies should minimize siting problems.

So modular units could offer several types of savings, beginning with cash-flow benefits. Timing is the key. If ten 100-MW units were ordered all at once, they would cost more and tie up more capital than an order for one 1000-MW unit. But phased orders in small increments allow a utility to commit less capital at any one time, and this could mean lower total interest costs on the borrowed capital.

Shorter construction times should add to the interest savings because the duration as well as the amount of the borrowing would be reduced. Certain large-scale technologies have special problems in this connection. Besides the extra time required to fabricate and assemble components in the field rather than the factory, nuclear plants, for example, must make retrofits to comply with any NRC regulations that are issued after construction has begun. Small-scale modular technologies would be less vulnerable to these burgeoning delays and carrying costs during the construction period.

Rapid modular construction would also speed the entry of new capacity into the rate base, allowing the utility to begin earning a return on its investment. The current AFUDC (allowance for funds used during construction) accounting system generally does not allow the plant cost to enter the rate base prior to completion. The bulk of it hits all at once, when the plant finally goes into service. The CWIP (construction work in progress) accounting method would provide for more evenly phased entry into the rate base during the construction period, but its use is often not permitted by public utility commissions. So substantial benefits can accrue simply from shortening the time it takes to bring new capacity on-line, and modular increments look very promising in this regard.

Modular generation could also offer cost savings associated with ease of siting. Because advanced modular technologies, like all the new technologies under development for power generation, are being designed for low environmental impact, expensive delays in the permit process should be minimal. Some modular technologies could use smaller sites than conventional plants require. And the ability to site power modules where they are most needed, close to load centers, may save on transmission costs.

Another potential benefit of the modular approach is increased system reliability. The hope is to reduce the impact of outages by spreading the risk over more generating units. For example, a string of ten 100-MW units is expected to provide more reliable service than one large 1000-MW plant because it is unlikely that all 10 modules would suffer outages at once. Even if interruptions did occur in one or more of the modules, the rest could go on producing power. A comparable outage in the large plant could make the full 1000 MW of capacity unavailable.

As Dwain Spencer, director of the Advanced Power Systems Division, views the situation, "The concept of modular, parallel systems became a requirement and then a reality in order to achieve the high reliability necessary for missile and space missions. Now we have to demonstrate that this same idea can be applied to advanced power systems."

The modular approach is not the only way to deal with the drawbacks of building expensive new capacity in a climate of uncertain demand and tight money. One nonmodular alternative is the effort to extend the useful life of existing plants, whatever their size, so that new capacity will not be needed so soon. Another is the possibility of utilities' buying electricity from other utilities that have excess capacity or buying it from third parties, perhaps cogenerators, who finance and operate their own generating equipment. Utility efforts toward conservation and load management make up the corresponding demand-side strategy for capacity deferral.

In those cases where there is no choice but to add new capacity, a number of utilities are sharing ownership. For example, four companies might share the financing and the risks of building one 800-MW coal-fired baseload unit, taking shares of 200 MW each. There are clear capital cost advantages to such an approach, given the economies of scale and the need for only one site. But institutional arrangements can become complicated, lead times are longer with a conventional coal plant, interest costs and transmission costs can rise, and the reliability issue is not addressed. So the shared-ownership option is not directly competitive with the modular option in every respect.

Modular candidates

Which technologies have modular potential? Possibilities include both the old and the new: traditional combustion turbines fired by oil or gas; renewables, such as hydro, geothermal, and wind; two new coal-based technologies, the integrated gasification–combined cycle (IGCC) and pressurized fluidized-bed combustion (PFBC); the rapidly evolving fuel cell; and storage batteries that could supplant the need for capacity expansion in certain systems.

Combustion turbines can be mass-produced in small-unit sizes and shipped to the site for rapid installation. Burning clean fuels, they have relatively low environmental impact and can even be sited in populated areas. Utilities long accustomed to using combustion turbines to meet daily demand peaks can also use them to provide small-capacity increments with minimal capital investment. One large utility has kept leased combustion turbines floating on barges in a nearby harbor for just such a contingency.

The drawbacks, however, are well known. Combustion turbines are costly to operate, requiring expensive fuels. "Their main advantage," says Stanley Vejtasa of EPRI's Planning and Evaluation Division, "is that they are available today," a comment on the fact that some of the more promising options are still out of reach.

Renewables present a mixed picture. Small-hydro installations carry no stiff penalty in regard to scale: at the lower end of hydro's very broad capacity range, small units of 1–15 MW and even micro units whose capacity is measured in kW can generate electricity economically. The number of suitable sites is limited, however, and concentrated mostly in the Pacific and Rocky Mountain states.

What's more, each site is unique. Many require custom treatment, making it difficult to achieve the kind of savings that come from use of mass-produced power modules. Where appropriate, though, the hydro market is using predesigned components to reduce capital costs, especially for small units.

The photovoltaic cell is a highly modular concept. It is intended to be small, mass-producible, easily transported, and adaptable to light resources at a great variety of sites. But it is still under development to resolve the technical unknowns in linking the cells together to produce power on a utility scale and to make it economically competitive.

Experimental wind machines have maximum capacities of about 2.5 MW. The aim is to scale them up to about 5 MW. Within the next five years we should know whether wind farms using large wind machines are economically viable for utility power needs. The potential for mass production of large 5-MW wind machines, using components that would be available off the shelf in the future, is a major asset in the cost outlook. Such methods are already being applied to the production of smaller (20–50 kW) wind machines.

Geothermal units inherently fall in a modular size range. The Heber hot water binary-cycle prototype now under construction in California will have a capacity of 45 MW and is slated for commercial service following its demonstration phase. Major components of the binary-cycle unit can be factory built, whittling capital and construction costs.

Geothermal wellhead power systems in the 2–10-MW range seem ideally suited for modularization. One such modularized system is the new rotary separator–turbine (RST) developed and tested by EPRI. This device increases the power yield from a geothermal fluid flow by separating its two phases, sending the steam to a conventional steam turbine and using the kinetic energy of the high-speed liquid to drive a specially designed hydraulic turbine. Wellhead power modules based on binary-cycle technology appear to have broad application, and a combined-cycle hybrid is under consideration for use with geopressured resources.

Geothermal units of all types, like hydro units, are rooted to their resource. Known geothermal resources are equivalent to 24 GW (e), with the resource base estimated to be about 120 GW (e). Most geothermal resources are thought to be located in the West, a rapidly growing region of the country.

IGCC: a new systems concept

Four other new technologies now under development could make the modular option accessible to utilities nationwide. The first of these to reach the point of demonstration is the IGCC.

Coal is converted at an elevated temperature to a combustible gas that fuels a combustion turbine after essentially all the pollutants present in the coal have been removed. The turbine's exhaust heat is then used to raise steam to drive a steam turbine, adding to the power extracted from the initial coal input. Steam from the gas cooler in the gasification section also flows to the heat recovery steam generator in the power section, augmenting the steam generated with the exhaust heat from the combustion turbine.

Most of the IGCC component subsystems are factory built and small enough to ship to the site by rail or barge. Construction lead times could range from three to five years. This new technology has the potential to use a broad range of coal types and still satisfy stringent environmental standards without postcombustion cleanup. An IGCC plant is expected to need only about 60% of the water required by a coal-fired steam power plant and 30–50% of the land.

Performance and cost projections for IGCC baseload power look promising when compared with the figures for conventional pulverized-coal plants with flue gas desulfurization. IGCC combustion turbines with a 2000°F (1093°C) inlet temperature are expected to offer a net heat rate of 9460 Btu/kWh, about the same as the rate for supercritical coal-fired plants and a significant improvement over the 9860 Btu/kWh rate for subcritical plants.

Capital costs are projected to be approximately $1130/kW for the new system, about the same as the roughly $1100/kW required for a conventional coal unit (December 1981 $). And the levelized cost of producing electric power is expected to be lower with the IGCC technology: about 90 mills/kWh in comparison with 93–95 mills/kWh for the pulverized-coal options. Further, these estimates are only for present federal emission control requirements. If we look at the more stringent standards that exist in some locations, the comparative advantages of clean-coal IGCC technology grow because conventional coal plants would be burdened by the parasitic power requirements and extra capital cost of the added cleanup equipment.

The preceding comparisons are based on plant capacities of 1000 MW. How would an IGCC plant fare if scaled down to a modular 250-MW capacity? Capital costs would increase to about $1500/kW. But efficiency would be little affected, with the heat rate increasing only slightly, to about 9750 Btu/kWh. The levelized cost of IGCC power production should remain competitive.

The 100-MW IGCC demonstration module now being constructed at Southern California Edison Co.'s Cool Water site will convert 1000 t/d of coal by Texaco coal gasification technology into synthetic gas for power production by using General Electric Co.'s combined-cycle equipment. Its aim is to gather actual modular cost and performance data while confirming that IGCC systems are competitive with pulverized-coal combustion systems. To secure the utility and vendor confidence necessary to make a new technology commercial, "you've got to get proof," emphasizes Seymour Alpert of the Advanced Power Systems Division. "And the only way you get that is to build a large demonstration plant and try it out on a utility grid to confirm your assumptions with regard to the actual components that make up the technology."

Plant availability will be a major focus of the monitoring. Large conventional coal plants have had significant outage and repair problems, as reflected by equivalent availability rates in the low 70s. IGCC plants, with their multiple gasification trains and turbines, are expected to offer an equivalent availability of approximately 85%. The data from Cool Water will help to optimize component arrangement for independent operation, exerting what is hoped to be an evolutionary effect on unit availability and system reliability in systems using IGCC units.

The turbocharged boiler

Another clean-coal technology with modular potential is PFBC. As with IGCC, the motivation for its development has been to use cheap, abundant domestic coals in an environmentally acceptable way for large-scale power generation. Those advantages are now amplified by the prospect that PFBC could ease the financial bind on utilities by generating power economically in small-unit sizes as well.

Burning coal at atmospheric pressure requires units that are generally too large to be factory built, at least for utility use, according to Kurt Yeager, director of the Coal Combustion Systems Division. But PFBC, operating at pressures of 10–15 atm (1.01–1.52 MPa), allows boilers of 100–250 MW capacity to be factory built in units of shippable size. Low emissions of sulfur and nitrogen oxides and high thermal efficiency are pluses for the pressurized units. And the fluidized-bed boiler is notably insensitive to fuel quality. In addition to using low-grade coals, this combustion technology can even operate on mine wastes and municipal refuse, a handy feature in times of fuel restrictions or rising costs.

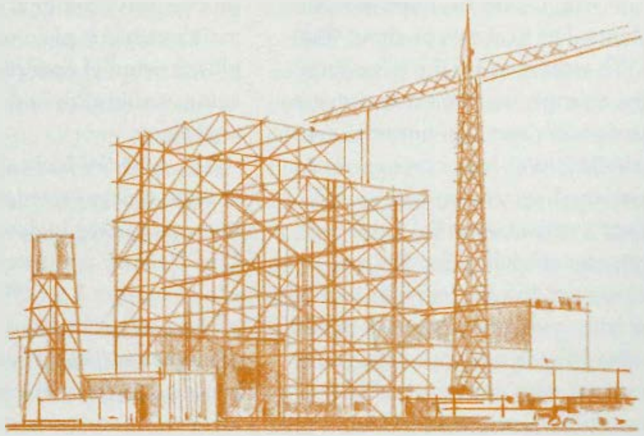
The PFBC system envisioned by EPRI centers on a turbocharged boiler, where coal is burned under pressure with dolomite in a turbulent bed of hot air. The dolomite removes sulfur from the combustion gas by chemical reaction, forming a disposable solid waste, while the combustion heat raises steam that drives a turbine to generate electricity. The flue gases are expanded through a gas turbine, which drives an air compressor that supplies air to the boiler. This is the low-temperature mode of turbocharged PFBC operation. Further in the future, the gas turbine could be driven by hotter combustion gases from the boiler and could also generate electricity, thus providing combined-cycle power production.

The small-scale turbocharged boiler is key in making modularity possible for coal-fired power plants, according to Steven Drenker of the Coal Combustion Systems Division. "The boiler is a critical-path item," he says, pointing out that the time saved by factory fabrication of other components would do little to speed plant construction if the boiler could not be produced in similarly rapid fashion. PFBC technology "offers the first opportunity to totally shop-assemble a utility-size boiler," Drenker continues. "Once you have a modular boiler, then you can go on to assemble the other subsystems necessary for a modular power plant."

Increasing the boiler inlet temperature and using the gas turbine for combined-cycle operation means greater efficiency but also greater technical risk. "We see that as a second-generation effort," comments Yeager. "We think that the way to get there logically is to first develop the turbocharged boiler capability and then to build on that experience."

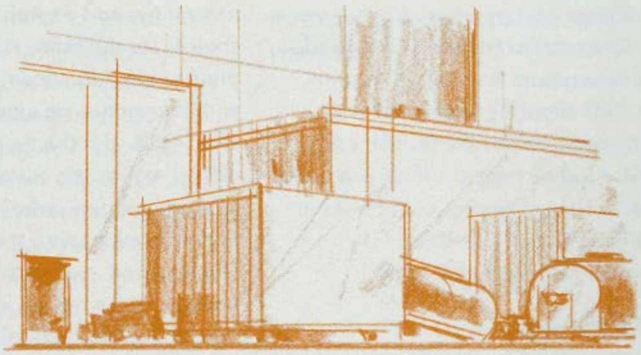
A 30-MW (e) equivalent PFBC pilot combustor is already operating at Grimethorpe in England, a 15-MW (th) PFBC component test facility is operating in Sweden, and a third PFBC pilot plant is under construction by Curtiss-Wright Corp. in New Jersey. Yeager envisions construction of a 50–100-MW (e) first-generation PFBC utility prototype in the turbocharged boiler configuration with EPRI cofunding in the late 1980s.

Modes of Power Plant Construction



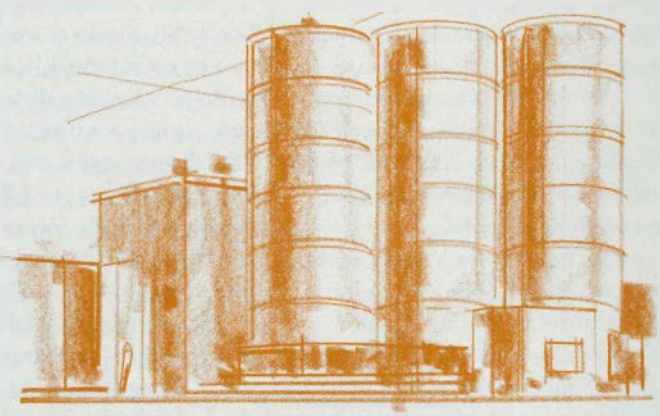
Field Fabrication

Constructing a power plant on-site to the specifications of an architect-engineer represents the extreme in custom design. It typically involves long lead times, the need for a large workforce in the field, difficulties imposed by weather, and the coordination of construction materials and quality control procedures. Baseload capacity is for the most part field-fabricated.



Shop Fabrication

Construction cost and lead times can be significantly reduced by prefabricating the major components of a custom-designed plant in a closed factory environment. These pieces are then shipped to the site for final assembly. Modular generation technologies under development that lend themselves to shop fabrication include gasification-combined-cycle systems and pressurized fluidized-bed combustion.



Factory Production

Unit cost, lead times, and deployment flexibility can be further improved through standardized plant design and mass production in a factory environment. This allows capacity expansion through procurement rather than construction. Such off-the-shelf availability and rapid installation are possible today with gas turbines and diesel engines; tomorrow the options may include fuel cells, small wind turbines, geothermal wellhead units, batteries, and photovoltaic arrays.

The performance projections for a 250-MW unit place PFBC in a competitive light with regard to conventional coal plants. The heat rate of about 9300 Btu/kWh estimated for the basic turbocharged arrangement would improve on standard pulverized-coal burning, and the 8340 Btu/kWh heat rate expected in full combined-cycle operation would represent a very substantial move toward greater efficiency. Studies now under way aim to establish the favorable capital and power cost potentials of PFBC technology. Tightened emissions standards would raise these costs slightly, but conventional plants would be hit even harder, sharpening the competitive edge of the PFBC option.

Proof awaits the demonstration of a fully configured PFBC generating system at utility scale. Yeager, citing the technical challenges of operating at pressures heretofore untried for fossil-fuel-fired power generation, notes that "maintenance and reliability have to be well demonstrated before the industry will buy this kind of system." If all goes well, the turbocharged system could be commercial by the early 1990s and the combined-cycle version by 2000.

The fuel cell option

The fuel cell, also still under development, is in many respects an ideal candidate for modular applications. The first entirely new generating technology since nuclear, according to Arnold Fickett of the Energy Management and Utilization Division, the fuel cell is simple in concept. It converts the chemical energy of a hydrogen-rich fuel directly to dc power without the need for intervening combustion or thermal cycles.

So compact that it was initially used to power American space vehicles, the fuel cell requires no scaling down. A single cell produces only 0.6–1.0 Vdc. The cells would be mass-produced and stacked into factory-fabricated modules for utility-scale use. Estimates are that the time from order to completed installation of a fuel cell power plant could be as little as two years. Fuel cells, since they essentially avoid the combustion process, have minimal emissions, the main one being plain water. This feature, plus their quiet operation and tidy packaging, would allow siting virtually anywhere.

The 4.5-MW fuel cell utility demonstration unit expected to begin operation this year is sited in downtown New York City. Densely populated Tokyo is the site of another 4.5-MW demonstration project, also scheduled to begin producing power in 1983. These efforts are expected to verify the fuel cell's siting advantages and consequent transmission savings.

Contrary to earlier fears about reliance on expensive fuels, the fuel cell can use hydrogen produced from a large variety of resources. Because of availability, natural gas and naphtha are the initial choices for the first-generation phosphoric acid cell, which handles them with conversion efficiencies in the range of 40–42%. But the first-generation fuel cell, as well as the advanced phosphoric acid and molten carbonate cells now under development, can also operate efficiently on coal-derived liquid or gaseous fuels. An option for the future—combining two technologies that are still very new today—is the concept of a coal gasification fuel cell power plant.

Meanwhile, the targeted heat rate for the first-generation fuel cell is 8300 Btu/kWh, fuel to ac busbar. The capital cost target is $660/kW for a 10-MW unit, including installation and interest costs during construction. Achieving capital costs in this impressive range, however, will require full-scale mass production of the fuel cell power plant components. This is the fuel cell's biggest problem.

"We're in a Catch-22," says Fickett, referring to the dilemma that plagues many a new technology. Only mass production will bring down costs enough to create a substantial market, but manufacturers are reluctant to make the huge investment required for mass-production facilities until they are sure that such a market exists. Over the past few years, with the reduced growth in electricity demand and the virtual standstill in utility orders for new generating equipment, the fuel cell's market has become too uncertain to justify large manufacturer investments. Uncertainties in future government funding have compounded the fuel cell's commercialization difficulties.

"The first-generation phosphoric acid fuel cell is very close to being ready in the sense of technical maturity," Fickett explains. "The real issue is whether the manufacturers are willing to invest the capital to build the facilities to produce fuel cells at the required cost and whether a simultaneous market will develop to absorb fuel cells at that cost."

Although IGCC and PFBC are new system concepts, most of their major components—the familiar gas and steam turbines, for example—have been in mass production for years. What's more, these components have established nonutility markets to sustain them during periods of flat electricity demand. The fuel cell, in contrast, is starting from scratch.

To be ready for the utility market that Fickett sees developing as load growth catches up with capacity in the early 1990s, the fuel cell needs a manufacturing commitment soon. Recognizing this need, EPRI has helped to establish a Fuel Cell Users Group to promote utility interest in fuel cells and to help manufacturers identify this interest. The Institute is also funding efforts by potential vendors to provide specifications that will move the technology up to full utility scale.

For planners at cash-starved utilities with uncertain load growth, the modular fuel cell is a hedge without parallel. Mass-produced modules could operate economically in increments as small as 10 MW and proliferate rapidly on demand. With fuel cells, Fickett points out, the planner "can wait until the last minute to make a buy decision."

Battery storage

A final piece in the modular mosaic is not a generating option at all. It is, rather, a substitute for new generating capacity. The storage battery, which is modular in its size, its ability to be mass-produced, its short lead time, and its siting flexibility, offers a variation on the modular theme.

Storage batteries can improve the use of existing central station generation by receiving low-cost electricity produced during the night and early morning hours and holding it for delivery until demand climbs later in the day. In the targeted unit size of 20 MW, batteries dispersed throughout the utility system and sited close to load centers could do much the same job as small, dispersed generation modules. Further, at the targeted capital cost of about $550/kW and fueled by off-peak electricity, they could produce power on peak at a lower cost than new generators could.

But storage batteries are about five years behind fuel cells in technical maturity, according to Fickett. The zinc chloride battery is the front runner, with the higher-risk yet more efficient beta (sodium-sulfur) battery hot on its heels. Even the dark horse lead-acid battery, reliable but long considered too expensive for large-scale utility use, is showing promise. Fickett points out that the cost of lead has dropped since 1975, while material costs for other battery types have risen, so the lead-acid battery may be economically viable after all.

The storage battery faces the same chicken-and-egg commercialization dilemma that confronts the fuel cell. Both require mass production to bring down costs. Fortunately, substantial help is ready in the form of the Battery Energy Storage Test (BEST) Facility cosponsored by DOE, EPRI, and Public Service Electric and Gas Co. (New Jersey).

The BEST Facility affords the battery developer a real-world evaluation of a new battery system before the commercial design is final, a process that promotes utility confidence in the resulting product. The zinc chloride battery is scheduled to begin long-term testing this year, with the advanced lead-acid battery probably following in 1984 and the zinc bromide or the sodium-sulfur battery slated for tests in 1985. Modular storage, like the newer forms of modular generation, still awaits technical confirmation and commercial acceptance.

The modular outlook

What, then, is the outlook for the modular option? What circumstances might prompt utilities to place modular units in their systems?

The recent abatement of inflation and the drop in interest rates might appear to relieve the building-cost bind on utilities, thus tarnishing the prospects for modular generation. But Vejtasa points out that borrowing rates to finance new construction are still very high, and that as the spread between these rates and a falling rate of inflation grows wider, it becomes more and more difficult for utilities to recover their construction costs through increased revenues. So economic trends in the first part of 1983 have made small increments more attractive than ever. A major utility construction contractor reports a recent upswing in preliminary design requests for small units.

Because each of the new modular options offers slightly different features, coming events may affect the prospects for each one somewhat differently. But some influences favor modularity across the board. First would be a continuation of those conditions that stirred initial utility interest: hard-to-predict demand patterns, coupled with cash-flow problems and long lead times for large units. Second, the successful demonstration of the new modular technologies at utility scale would furnish an essential bridge from potentiality to reality. Proof of the modular concept in its various forms could help create a firm utility market and secure the necessary manufacturing commitments.

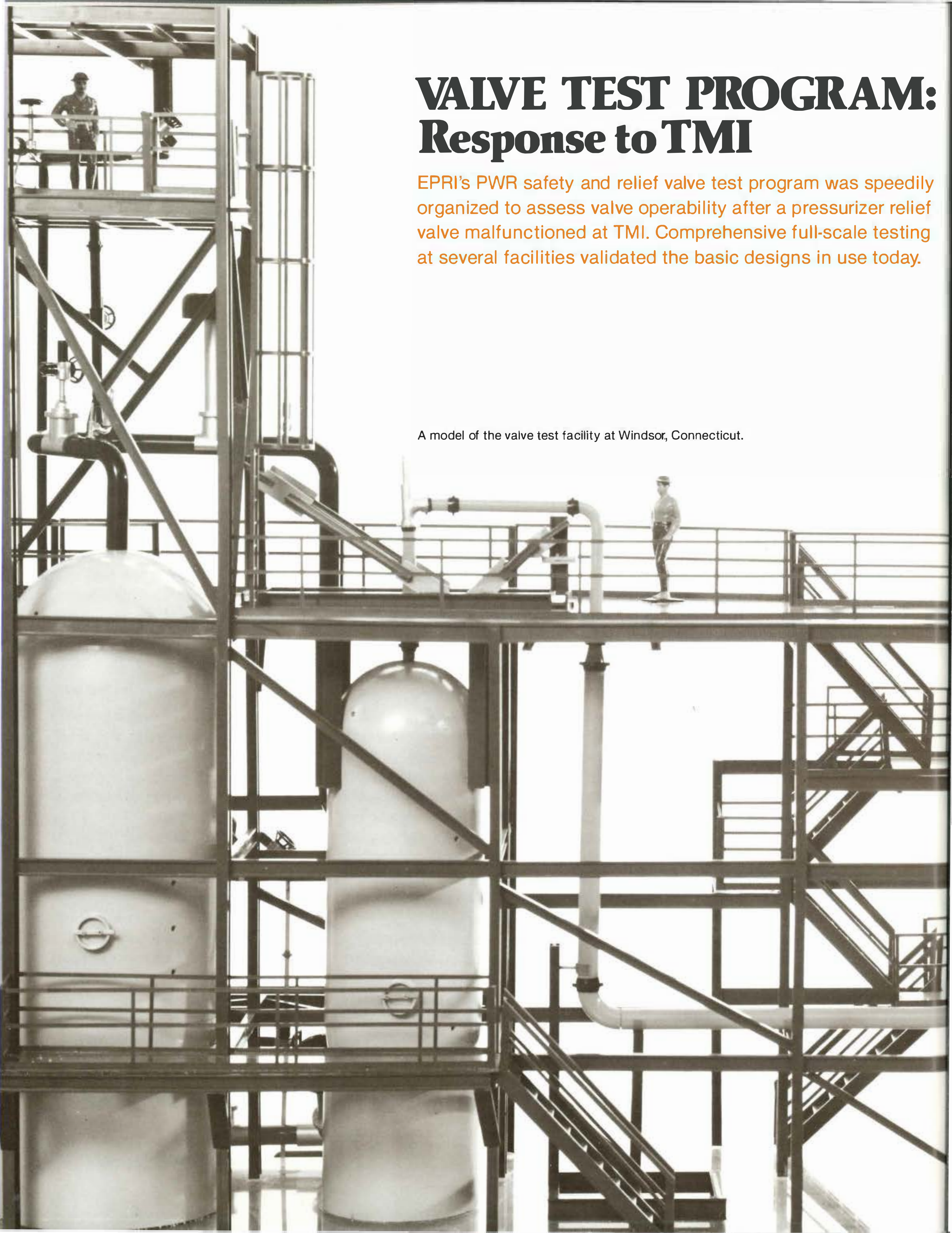
In the view of Fritz Kalhammer, director of the Energy Management and Utilization Division, the modular approach is "part of a broad trend toward integration of relatively small-scale, dispersed electricity sources into utility systems." Yeager adds that the conditions prompting utility interest in modular increments may be quite persistent. "I don't think we're looking at a situation that's going to go away in 10 years," he says. "I think it's something we're going to be faced with for a long time."

The modular approach could offer more than a short-term solution to the utility cash-flow bind. It could offer a viable long-term strategy for living with demand uncertainty. Bigger will still be better in many applications, but as long as tight money and doubtful demand prevail, small modular units may fill a special need in prudent utility planning. ■

This article was written by Mary Wayne, science writer. Technical background information was provided by Dwain Spencer and Seymour Alpert, Advanced Power Systems Division; Kurt Yeager and Steven Drenker, Coal Combustion Systems Division; Fritz Kalhammer and Arnold Fickett, Energy Management and Utilization Division; and Richard Zeren and Stanley Vejtasa, Planning and Evaluation Division.

VALVE TEST PROGRAM: Response to TMI

EPRI's PWR safety and relief valve test program was speedily organized to assess valve operability after a pressurizer relief valve malfunctioned at TMI. Comprehensive full-scale testing at several facilities validated the basic designs in use today.



A model of the valve test facility at Windsor, Connecticut.

August 1979: EPRI was asked to carry out full-scale operability testing of safety and relief valves by the electric utility industry's PWR owners because of the malfunctioning of a pressurizer relief valve during the TMI accident in March 1979. Timing was critical because of the implications to plant safety. And the job was enormous: although the valves had been tested under certain pressure and flow conditions, no full-scale data existed for the entire range of possible plant conditions and connecting pipe configurations. And no suitable testing facilities existed for this broad scope. Thus the program started almost at square one.

Reasons behind the tests

The PWR owners' desire to confirm the operability of the safety and relief valves that help safeguard PWR primary systems from overpressure was shared by the Nuclear Regulatory Commission. NRC's NUREGs 0578 and 0737 documented its requirements for the tests.

The work had high priority. EPRI's Nuclear Power Division would have to categorize the kinds of valves and piping configurations used in PWRs and the conditions under which they were used; select a representative group of valves for testing; establish detailed test conditions for the valves; define piping configurations that would encompass the conditions in existing nuclear plants; modify (and in one case, build from scratch) suitable test facilities; and finally, test the valves and get the results to the PWR owners—all by a deadline of July 1, 1981, established by NRC.

A job like this required special attention, and the division quickly established its PWR safety and relief valve test program, a $22 million effort funded not only by EPRI and 42 domestic PWR owners but also by five foreign organizations, two nuclear steam supply system (NSSS) vendors, one valve vendor, and one architect-engineering firm. A staff was speedily assembled, and by the autumn of 1979, team members were rolling up their sleeves and tackling the program's initial task: identifying the valves used in PWRs, the conditions under which they were used, and the facilities where the tests would be carried out.

There were some 103 PWRs operating and under construction, and no central, definitive list telling exactly what valves were used where, according to John Carey, who managed the program from August 1979 through September 1981. To ensure that the test program represented the full range of valves in use at each participating utility's plants, EPRI project managers had to categorize all safety and relief valves at all 103 PWRs.

Fortunately for the prompt implementation of the test program, EPRI's Nuclear Safety Analysis Center had conducted a preliminary, post-TMI survey of PWR valves, operating conditions, and test facility requirements. The Nuclear Power Division's Safety and Analysis Department had also done some studies on various aspects of valve operability. All this information proved useful in planning the new valve program and getting it off to a running start. The valve team took the available information and then went out to collect more data through surveys, interviews, and file searches conducted with the cooperation of the PWR owners, the NSSS vendors, and the valve manufacturers.

Not only did all the safety and relief valves used in PWRs have to be fully categorized, but the valve team also had to decide which of the dozens of different valves to test. PWRs used a wide range of valves from different vendors and manufacturers, and there were important differences between some valve types. Yet many valves were simply smaller or larger versions of the same valve or were versions that were only slightly different. EPRI commissioned valve manufacturers to recommend representative safety and relief valve types, models, and sizes for testing. Engineering evaluations were carried out to determine how operability would be affected by differences in valve operating characteristics, materials, design details, and sizes. Ten power-operated relief valves and seven safety valves were eventually chosen for testing.

After the test valves were selected, test conditions had to be established. The NRC regulations designated basic test requirements, but specific conditions in the PWRs also had to be identified. The EPRI team asked NSSS vendors to define the expected range of valve conditions in all 103 PWRs, which covered an array of piping configurations, operating conditions, and other parameters that varied from unit to unit. After considerable research, the various conditions were collated, and from them critical test facility requirements were specified, including maximum test pressures, temperatures, flow rates, pressure ramp rates, and the range of fluid conditions at the valve inlets.

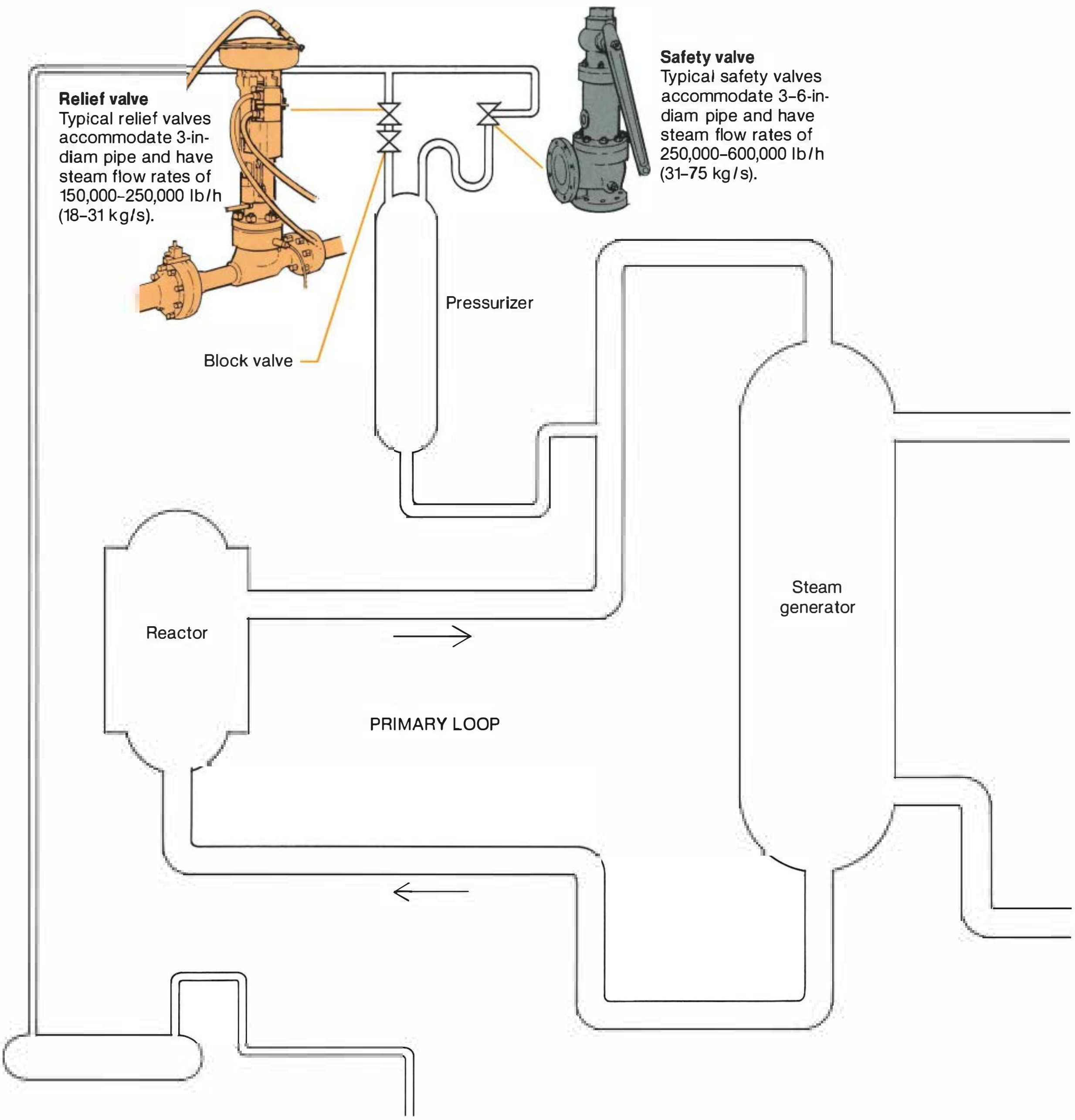
Because the choice of valves and test conditions had to be meticulously documented to satisfy NRC licensing requirements, a quality assurance program was organized to justify the choices of valves and the tests. EPRI received guidance from the PWR owners through an intricate network of advisory groups, including a subcommittee of the Research Advisory Committee (at the time, RAC was chaired by Russell C. Youngdahl), the Safety and Analysis Task Force subcommittee on the valve program (chaired by David P. Hoffman), and a technical advisory group for the valve program (chaired by James F. Scott). Through these advisory groups, utilities could participate in the test program whose results they would ultimately present to the NRC.

Finding facilities

By the end of 1979 EPRI had a reasonably good idea of what valves would be tested and under what conditions. The laborious finalization of these choices was to continue for months, but meanwhile, the team could begin its search for facilities capable of performing the full-scale valve tests under a variety of conditions, according to Warren Bilanin, who took over as

OVERPRESSURE PROTECTION FOR PWRs

Water in the primary loop carries heat from the reactor to the steam generator and then returns to the reactor. To prevent the water in the loop from boiling, the system is kept under constant pressure by a pressurizer connected to the primary loop. If temperature and consequent pressure in the pressurizer become too high, the relief valves atop the pressurizer will open to release steam and reduce pressure. The safety valves provide the final protection against overpressure, opening in the rare instances when steam flow is greater than the relief valves can accommodate. Most PWRs have both types of valves, although only safety valves are required by ASME codes. There may be up to three of each type of valve installed above the pressurizer. Both types of valves, which typically range from 2 to 6 ft tall, open and close automatically in response to pressure transients. Relief valves are operated by an external power supply, usually controlled by electric signals; safety valves are self-actuated, opening at preselected pressures.



program manager in October 1981.

It was clear from the start of the program that no existing valve test facility could accommodate the larger of the two valve types—the safety valves—and provide the many test conditions required. So in January 1980 EPRI commissioned Combustion Engineering, Inc. (C–E), to design and build a facility that could. The $8 million structure was to be capable of testing all valves, including the safety valves, under a full range of conditions. The facility would also include instrumented inlet and discharge piping to simulate the effects of piping on valve operability and to permit the measurement of data to verify piping load models. Construction began in early 1980 at Windsor, Connecticut, and proceeded at full throttle.

Yet time was already getting short in the race to complete the tests by the NRC's deadline. The C–E facility couldn't possibly be completed before early 1981, leaving at best a handful of months in which to perform the valve tests. EPRI had to find test facilities that could be used immediately—if not for the safety valve tests, at least for the relief valve tests.

Luckily, Duke Power Co.'s Marshall Steam Station in Terrell, North Carolina, had a basic valve test facility that Duke used for in-house tests. The facility, which included a source of 2500-psi (17-MPa) steam, was generously offered to EPRI for use in the valve test program. After minimal modifications to the facility, the first relief valve tests began at Marshall in June 1980. These tests were under the steam-only conditions that the valves would be most likely to encounter.

The relief valves still had to be subjected to test conditions that included subcooled water, saturated water, steam-to-water transitions, and water-seal fluid conditions; such conditions were beyond the existing steam-only capability of the Marshall facility. Wyle Laboratories maintained a high-pressure water test facility at its test complex in Norco, California, and this facility could furnish the additional relief valve test conditions, although considerable modifications to the facility would be necessary. EPRI decided to finance the modifications, and relief valve tests at the Wyle facility began in October 1980. Between the Marshall and Wyle facilities, all relief valve tests were completed by the NRC's July 1, 1981 deadline.

Meanwhile, at the C–E facility, construction was going full tilt: work proceeded on three shifts a day, and every effort was made to expedite the pace. For example, when the two pressure vessels were to be shipped by rail from the manufacturer in Chattanooga, Tennessee, to the test facility site in Connecticut, EPRI opted to pay for direct shipping on dedicated cars. Carey explains that this spared about three weeks' travel time over the usual circuitous rail route and ensured that the vessels would not be temporarily sidetracked in some out-of-the-way railyard. The hustle paid off: the new facility was designed and constructed by April 1981—a mere 15 months.

Initial tests at the facility showed some deficiencies in safety valve performance, necessitating an increase in the number of tests, which required an increase in schedule and cost. The utilities promptly responded to this need, agreeing to the increase in testing, schedules, and budget. NRC, convinced that the industry was working hard to complete the valve tests as quickly as possible, granted a one-year extension of the deadline to July 1, 1982. Testing of the safety valves at the C–E facility began in June 1981 (also on three shifts a day) and ended in December 1981, concluding the test phase of the program.

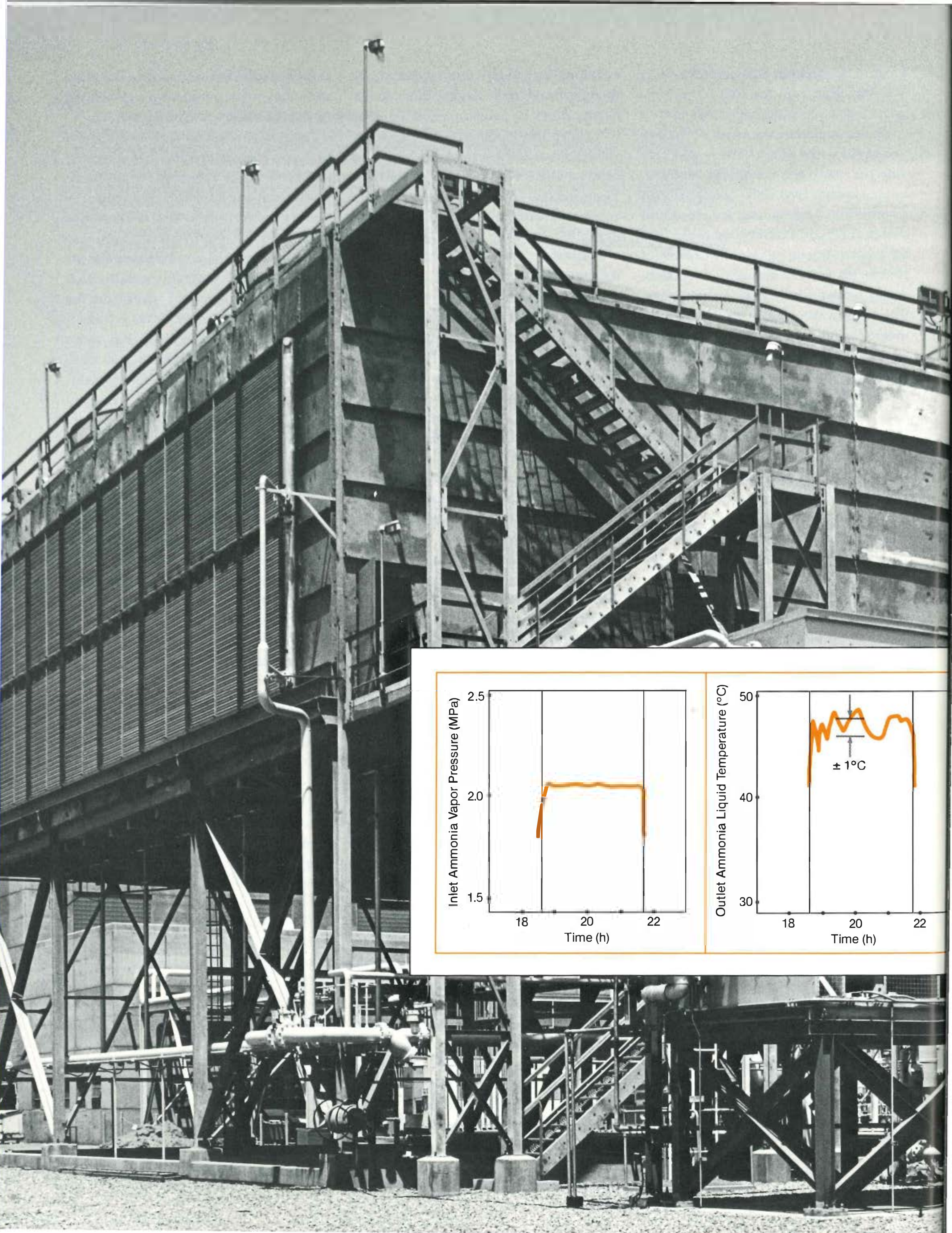
Results are in

Valve test results from all three facilities were compiled by April 1, 1982. They were immediately turned over to the PWR Owners Group in the form of seven volumes of reports. The group in turn delivered the reports to NRC. The utilities still had time to do preliminary evaluations of their safety and relief valves well before the July 1 deadline. The relief and safety valve program was completed on time and even under budget.

As for test results, the news for PWR owners was good: performance was satisfactory for relief valves under all conditions, and performance was generally satisfactory for safety valves. There was some room for improvement in the case of safety valve systems, however. For instance, the test program revealed that when the inlet piping that runs from the pressurizer to the safety valves is unusually lengthy, pressure drops can cause safety valves to flutter open and shut, or chatter. Excessive chatter may damage the valves or reduce flow. The study showed that valve ring settings can usually be adjusted to eliminate or minimize chatter.

Utilities are now conducting in-depth plant-specific evaluations of PWR safety and relief valves where necessary, guided by the findings of the valve study. Where improvements can be made, such as adjusting valve ring settings, they are being carried out. The end result is more reliable nuclear plants. "The EPRI PWR safety and relief valve test program is a credit to our industry," sums up Youngdahl, executive vice president for corporate planning, Consumers Power Co. "Its completion under budget and on time demonstrated again that EPRI and the utilities can establish and accomplish well-designed programs. The EPRI staff and several dedicated utility representatives were able to address the concerns regarding PWR safety and relief valve operability by designing and executing comprehensive testing. The results of the valve test program are now available to the entire industry, providing data on which to base current decisions, as well as a foundation to assist in future designs that could further improve the operability of PWR safety and relief valve systems." ■

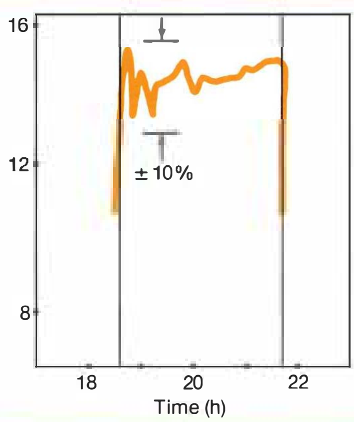
This article was written by Nadine Lihach. Technical background information was provided by Warren Bilanin and John Carey, Nuclear Power Division.



Inlet Ammonia Vapor Pressure (MPa)
2.5
2.0
1.5
18
20
22
Time (h)
Outlet Ammonia Liquid Temperature (°C)
50
40
30
± 1°C
18
20
22
Time (h)

COOLING WITHOUT WATER

Shakedown tests are under way on advanced ammonia-based cooling at a heavily instrumented test facility in southern California. Favorable results could open the door to greater economy and siting flexibility for power plants in water-short areas.



Ammonia vapor from the condenser-reboiler is condensed in the elevated cooling tower, using one of two advanced heat exchanger designs that minimize the need for cooling water. Data plots for the cooling tower indicate the operating steadiness of vapor pressure, liquid temperature, and liquid flow.

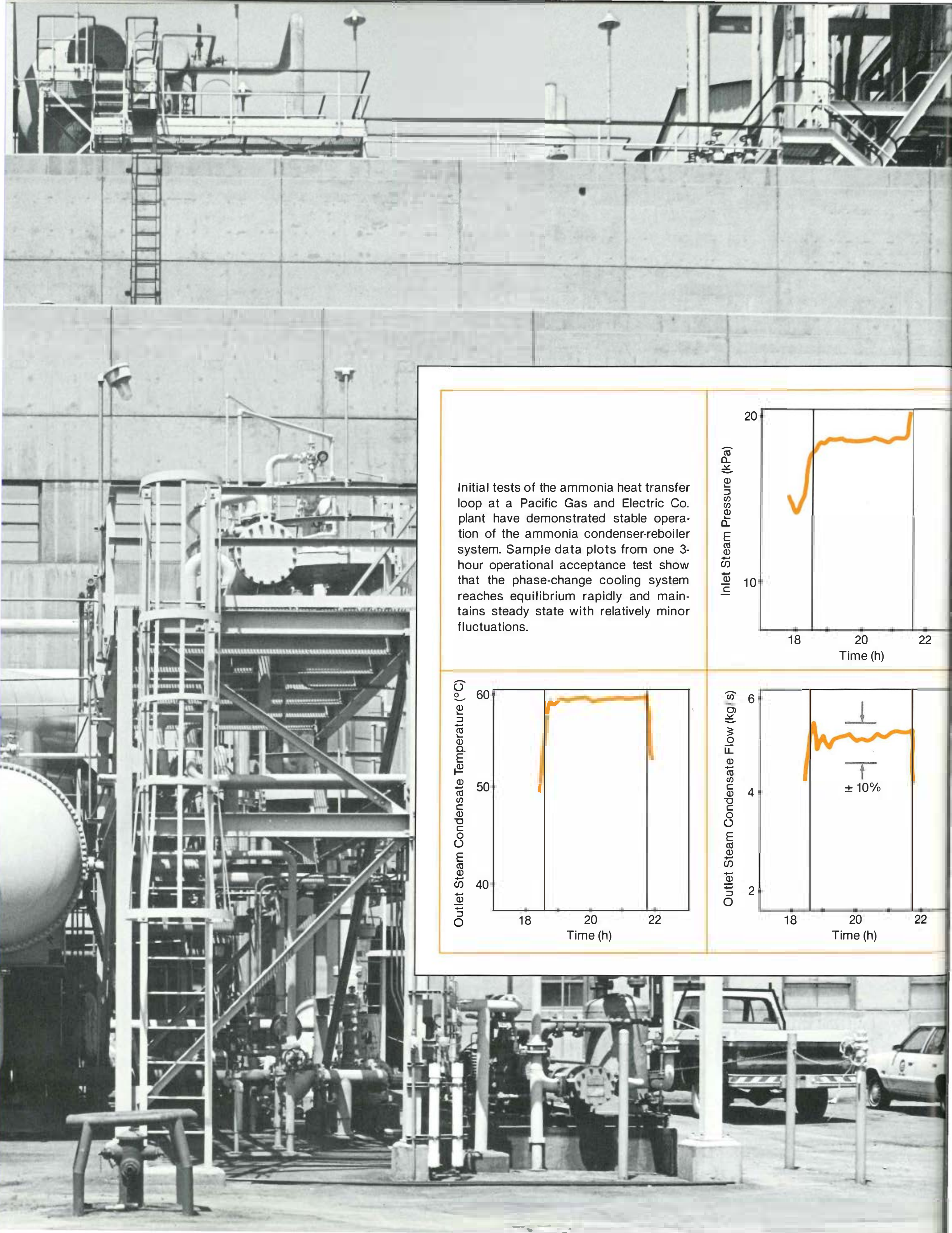
Geographic and institutional limits on the availability and use of water for power plant cooling are sending electric utilities in some parts of the country in search of water-conserving cooling systems. Demand for such systems is expected to grow in coming decades, despite high costs and efficiency penalties associated with the dry-cooling technology now available. An advanced cooling system under development by EPRI and interested utilities promises to significantly reduce typical plant cooling-water requirements and improve plant-siting flexibility. A $15 million project to demonstrate the advanced design is in the second of three years of testing at Pacific Gas and Electric Co.'s (PG&E) Kern station near Bakersfield, California, where success could lead to more cost-effective, water-conserving cooling systems.

Results from initial shakedown tests have been encouraging; stable, safe operation of the advanced system has been demonstrated and valuable insights have emerged with respect to component performance and interaction in an operating plant environment.

Reversing a trend

Cooling is not the only use for water in power plants; ash sluicing, stack gas scrubbing, boiler makeup, plant washing, and sanitary uses all require significant quantities. But cooling accounts for the largest share of a plant's water demand, as much as 75–95%, and offers the greatest potential for water conservation.

Until the late 1960s, waste heat rejection at most power plants in the United States was handled by once-through cooling systems. Such systems involve the one-time flow of large volumes of fresh water through the plant and return of the slightly warmed water to its immediate source. Little water is actually consumed in a once-through system, but



Initial tests of the ammonia heat transfer loop at a Pacific Gas and Electric Co. plant have demonstrated stable operation of the ammonia condenser-reboiler system. Sample data plots from one 3-hour operational acceptance test show that the phase-change cooling system reaches equilibrium rapidly and maintains steady state with relatively minor fluctuations.

the required water withdrawal volume is very high. A large coal-fired plant using once-through cooling and ash ponds typically may require the withdrawal of as much as 500 gal/min (3.15×10^{-2} m^3/s) for each megawatt of generating capacity.

The high water withdrawal requirements of once-through systems and regulatory limits on the allowable thermal pollution of rivers and streams contributed to the industry's adoption of evaporative cooling systems over the last decade. In this approach to plant cooling, heat from the turbine exhaust steam is transferred to a water loop; some of the water is then evaporated in large cooling towers. Evaporative systems require as little as 2% of the water withdrawal of once-through systems, about 10 gal/min (6×10^{-4} m^3/s) per MW (e), but the actual consumption of water by evaporation is as much as 300–500% greater. An evaporation-cooled 1000-MW (e) coal-fired plant consumes, on average, about 16,000 acre-feet (19.7×10^6 m^3) of water per year, which is roughly equivalent to the annual requirements of a community of 90,000 people.

Thus, although the technologic progression in cooling systems solved one cooling problem—high withdrawals—it also created a new problem—high consumption. This trend toward greater water use is expected to continue as more once-through plant cooling systems are replaced with evaporative systems. In some areas, however, growing competition for finite local water supplies is proving to be an obstacle to the conversion of plants to evaporative cooling and is in turn motivating considerable interest in dry, or water-conserving, cooling systems.

Dry alternatives

Dry-cooling systems can reduce a plant's cooling water requirements to essentially zero, but not without a toll in efficiency and cost. Economic evaluations of water-conserving cooling systems must necessarily consider the cost of using water for cooling versus the cost of not using it. In most cases, the cost of water is a relatively insignificant factor in the cost of power production, ranging from 1 to 3% for a plant of typical capacity factor and capital and fuel requirements. As long as water is available for cooling, there is no economic incentive to conserve.

When water is not available, however, the cost of cooling takes on a different dimension. Dry-cooling systems are substantially more expensive than conventional systems. The efficiency penalties and the need for larger heat transfer equipment mean that dry systems, even when plant-optimized, are generally three to five times more costly than wet-cooling towers in combined capital and operating costs. Power generated in plants that use the available dry-cooling technology costs, on average, 10–15% more than power produced in an evaporation-cooled plant and 15–20% more than power from plants that employ once-through cooling. Further, dry-cooling systems are generally less efficient in removing waste heat from a plant during the summer. This is because a dry system's heat rejection capacity is impaired at high ambient air temperatures, and such systems usually require turbines that are designed to operate at higher-than-normal exhaust pressures.

Two types of dry-cooling systems are in use in the United States, but only in isolated cases where special circumstances (fuel availability and water unavailability) outweigh the cost and efficiency penalties. A wet-dry system at the 466-MW (e) San Juan III power plant near Farmington, New Mexico, cools hot water from a steam condenser in dry-cooling coils. The San Juan unit, the largest wet-dry system in the United States, is owned by Public Service Co. of New Mexico and Tucson Electric Power Co.

Another dry approach is direct steam condensation, such as that used at the 330-MW (e) Wyodak plant near Gillette, Wyoming. In this system, the intermediate water loop is eliminated and steam is condensed directly by air in dry-cooling coils. Because the system requires only one heat exchanger rather than two, capital costs are lower and thermal efficiency is higher.

But direct steam condensation requires large-diameter ducts to carry the high-volume, low-density turbine exhaust steam to the cooling towers at an acceptable pressure drop. This limits the size of power plants that can use such a system. Larger stations would have to incorporate several smaller cooling units. Both the San Juan III and Wyodak systems are at minemouth power plants, where the economics favor dry cooling over the cost of long-distance coal hauling.

Advanced design

An advanced alternative dry-cooling system under development by EPRI and a group of utilities promises lower capital costs and greater plant efficiency over current dry systems by using a phase-change loop with ammonia as the heat transfer medium. Water savings afforded by the design can be substantial, although there is no identifiable upper bound on potential water savings because economics and water availability are specific to each individual power plant. In the advanced design, liquid ammonia is vaporized and passed through a phase separator, which sends the ammonia vapor to the cooling tower and combines the remaining liquid with condensate from the tower in a closed two-phase loop. Heat transfer enhancements in the ammonia condenser-reboiler, combined with the thermodynamic benefit of constant-temperature heat transfer, permit operation of the system at lower steam pressure and temperature than commercially available dry or wet-dry systems. The nearly isothermal phase-change approach is an inherently more thermodynamically efficient process than is sensible (temperature differential) heat transfer employed in a closed-water-loop cooling system, according to John Maulbetsch, manager of EPRI's Heat, Waste, and Water Management Program in the Coal Combustion Systems Division.

The ammonia system is designed for

NEED FOR DRY COOLING

Viewed as a geographic whole, the United States is water-rich; its population uses only 8% of total average rainfall, and the remainder runs off to the sea or evaporates. But rain that falls in Kansas is of no benefit to people in Phoenix, and the wide regional variations in supply mean frequent, sometimes severe, shortages. Moreover, these water deficits are centered in regions where expanding populations and attendant demands for food, energy, and water compound the cooling-water problem faced by electric utilities in those areas.

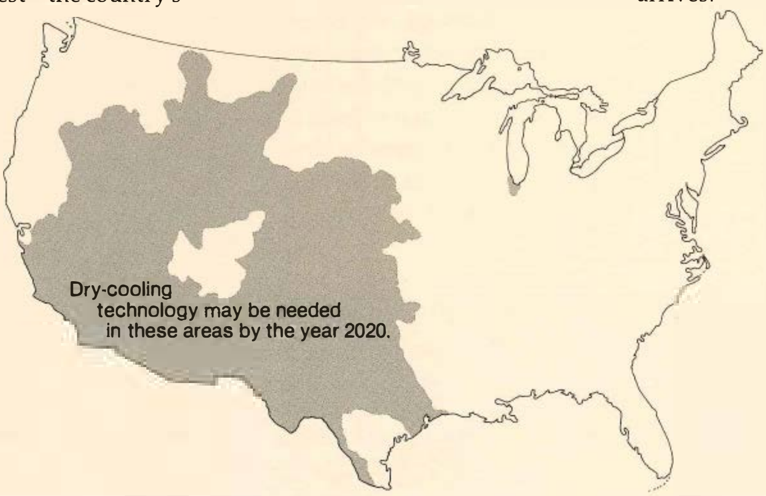
Compared with the use of water for agricultural irrigation, the energy sector's water demand is relatively modest. Irrigation accounted for over 80% of total freshwater consumption in 1975, while energy-related use (mostly for steam-electric generation) claimed only 1.3%, according to the U.S. Water Resources Council. Percentage comparisons, however, averaged over the 48 coterminous states, obscure the very real shortages that result from the confluence of population growth and energy demand in areas not naturally endowed with abundant water resources.

In the arid Southwest—the country's fastest-growing region according to 1980 census figures—major cities are already watching local water tables plunge with successive groundwater overdrafts. Because much of the nation's untapped coal and shale oil reserves are found in and near the Southwest, coal is seen as the most likely energy resource that will be used to meet the expected growth in electricity demand in the region. Yet according to a 1981 analysis for the U.S. Department of Energy by Hanford Engineering Development Laboratories (HEDL), as much as one-third of the projected increase in the use of coal will be limited by lack of reliable water supplies for cooling and other uses.

Water supplies for cooling existing electric power plants are relatively assured. Current interest in dry-cooling technology, however, is motivated by the clear potential for water considerations to become a serious obstacle to expanding generating capacity and replacing existing plants as they retire.

Competition among the nation's chief water-consuming sectors promises to get worse before it gets better. Although the withdrawal of fresh water for electric generation is expected to decline slightly over the next two decades, from about 89 billion (10^9) gal/d to about 79 billion gal/d by 2000, the industry's actual consumption of water is increasing. The growing use of evaporative cooling towers in place of old once-through cooling systems is projected to boost the utility industry's water consumption nearly eightfold, from about 1.4 billion gal/d in 1975 to 10.5 billion gal/d by 2000.

Given the coincidence of population trends, energy demand, and abundant energy resources in those parts of the country where water availability is already posing a barrier to development, it is expected that the need for dry-cooling systems will be substantial by the end of this century. The HEDL analysis estimates that from one-fourth to as much as one-half (70–140 GW) of the electric generating capacity that might be needed in the United States between now and 2020 will require some kind of advanced dry-cooling technology. EPRI's research in dry cooling is intended to ensure that the technology will be in hand—that is, technically proven and affordable—when the need for it arrives. □



water-augmented cooling during periods of high ambient temperature, further reducing the operating and efficiency penalties. In one design being tested, a conventional heat exchanger is added to the system on those days when supplemental heat rejection is required. In another design under evaluation, the heat exchanger surfaces are deluged with water for cooling augmentation.

Economic analysis of the ammonia-based system indicates a potential cost saving of about 35% over a conventional dry, closed-water-loop system on the basis of capital and operating costs averaged over the life of a power plant. Projected cost of power at the busbar is also about 35% less, compared with conventional dry cooling.

Performance projections for the phase-change design have been verified at laboratory and pilot-plant scale. To demonstrate operation and reliability of the system in a working power plant environment, EPRI funded design and construction of an advanced concepts test (ACT) facility at PG&E's Kern station. Construction began in 1980 and was completed the following year by C. F. Braun & Co. under the direction of Battelle, Pacific Northwest Laboratories. EPRI is joined by a group of electric utilities in sponsoring and funding the operation and testing phase that will continue into 1984.

The 140-MW (e) oil-fired Kern station was chosen for the test site because it offered an isolated turbine of a size considered acceptable for testing (about 10-MW [e] heat rejection equivalent) and because high summer temperatures (up to 133°F, 45°C) will provide an appropriate test of the heat exchangers. Heavily instrumented for collecting data, the ACT facility is designed to condense about 60,000 lb/h (7.56 kg/s) of exhaust steam from the plant's No. 1 house turbine that serves as an independent power source for the station auxiliary systems.

As a power plant cooling medium, ammonia is something of a departure from typical electric utility experience, although it has long been used for heat transfer in other industries. Ammonia's physical properties make it particularly suited for dry-cooling applications. Its high latent heat capacity and high density mean ammonia can hold more latent heat per unit volume in vapor or liquid than water or other fluids, contributing to its efficiency in heat transfer. Ammonia's low freezing temperature (−108°F, −78°C) also makes it suitable for power plant cooling in cold climates where freezing discourages the use of wet systems.

Development of an ammonia phase-change system for power plant cooling was originally suggested to EPRI by the Linde Division of Union Carbide Corp. Linde's steam condenser–ammonia reboiler, incorporated in the ACT design, differs from a typical plant surface condenser in that the liquid ammonia is vaporized on the tube side of the heat exchanger as steam is condensed on the shell side.

Two types of air-cooled heat exchangers in the cooling tower are being evaluated at the ACT facility. A dry exchanger with skived (shaved) aluminum fins for greater heat transfer surface was developed by Curtiss-Wright Corp. The unit, which can be water-augmented with an evaporative heat exchanger when necessary, is expected to have good resistance to corrosion and fouling because the surface of the dry exchanger is never exposed to cooling water.

Studies by Battelle show that if a small amount of water (1–10% of the annual water consumption of a wet-cooling system) is used to supplement the dry-cooling tower on the hottest days, savings of as much as 20% can be achieved over the cost of an all-dry system. To explore this potential, a wet-dry heat exchanger design for direct water deluge of exchanger tube fins is also being evaluated. The concept of water-deluge heat exchangers for power plants originated with the Höterv Institute of Hungary; a similar design is employed in the ACT water deluge exchangers manufactured by the Trane Co.

Four Curtiss-Wright skived-fin dry exchangers and 14 Trane wet-dry exchangers are housed in a 60-ft-long by 30-ft-wide (18 × 9-m) elevated tower built by Hudson Products Corp. Four 16-ft-diam (5-m) fans provide mechanical draft to the tower, which is elevated 24 ft (7 m) above ground.

A special feature of the ACT facility is the data acquisition system that monitors and records all aspects of the phase-change loop and heat exchangers in operation. About 150 sensors throughout the facility are connected to the system, which has a capacity for up to 250 sensors. Instrument readings may be collected as frequently as every 15 seconds, providing a statistical profile rather than simply a frozen snapshot of the operating system. The data are stored on magnetic tape for computer reduction and analysis.

A capacitive cooling system is also being tested at the ACT facility. With a water tank that functions as a thermal capacitor, the system is designed for thermal peak-shaving (balancing the heat rejection capacity of the dry system by storing excess heat during peak daytime periods for rejection at night). A heat pump is included in the heat rejection loop. Operation of the capacitive system, which functions in a zero-water-consumption, zero-discharge mode, is expected to begin this year. The unit was built by Chicago Bridge & Iron Co.

Test phase

In addition to evaluating the phase-change system's overall performance and its compatibility with power plant operations, the ACT facility is intended to experimentally address other technical questions as the next step leading to commercialization of cost-effective dry-cooling systems.

The aluminum heat exchangers must withstand corrosion and erosion, and the air-cooled exchanger surfaces must resist fouling and plugging.

Ammonia leakage from the steam loop must be avoided. The facility contains about 20 tons of ammonia—about as much as a typical tank truck. Demonstration of the safe handling of large quanti-

Worldwide interest in dry-cooling technology is growing as more countries find national energy development plans limited by plant siting and water availability considerations. Israel, for example, faces the dilemma of providing expanded generating capacity to meet its growing need without further encroachment by power plant construction on its short, heavily populated Mediterranean coastline. Dry-cooling towers are under consideration as an alternative to pumping large volumes of seawater long distances to cool inland power plants.

In Eastern Europe, landlocked Hungary has a long history of interest in water-conserving cooling systems. The Höterv Institute in Budapest pioneered the design of water-deluge heat exchangers for wet-dry cooling of power plants (a similar version of which is being tested at EPRI's ACT facility) and the Gagarin power station recently incorporated water-deluge exchangers into a dry-cooling system. The Soviet Union is operating indirect, closed-water-loop cooling systems at three power plants, including the 48-MW nuclear electric and district steam heating plant at Bilibino in northeastern Siberia.

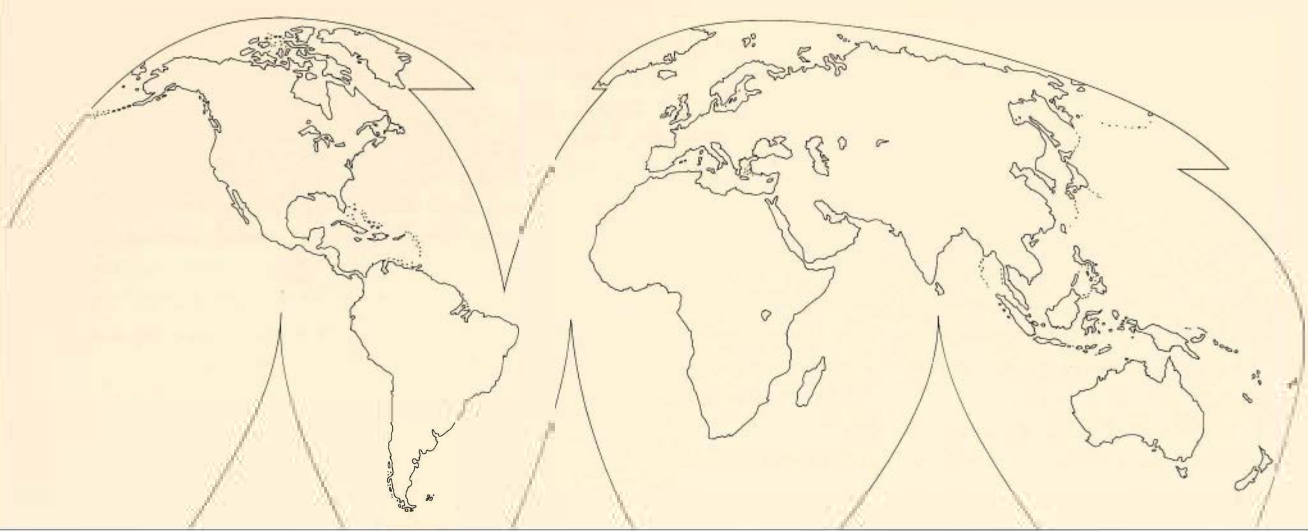
When specially designed, as at Bilibino, dry-cooling systems can be used in cold weather climates where freezing problems rule out the use of evaporative systems. A direct condensation system is in use in the United States at a 50-MW (e) plant on the Alyeska oil pipeline, and another of similar size and design is under construction by Chugach Electric Co. near Anchorage, Alaska.

The world leader in installed dry-cooling capacity is South Africa, where all-dry direct condensation cooling will be employed at the massive Matimba station. Located near South Africa's large coal deposits, the Matimba station, now under construction, comprises six 650-MW (e) units.

Other nations known to be investigating dry-cooling technology include Australia, where the motive (similar to South Africa's) is to develop coal resources without major inland water supplies; Canada (for its vast western provinces); the People's Republic of China; and Iran, where dry cooling is used at the Istfahan station near Tehran.

But perhaps the most advanced development of dry cooling is in France, where Electricité de France (EDF) has taken the next step in tieing ammonia-based cooling technology to power plants by adding a bottoming cycle turbine to the ammonia loop. The French have found the binary-cycle approach particularly suited to winter-peaking conditions and report that greater thermal efficiency and added power production should make the system comparable in cost to conventional evaporative cooling.

EDF has operated two ammonia test loops for the binary-cycle design since 1975, and a 20-MW (e) demonstration facility is nearing completion at the Gennevilliers power station near Paris. Plans are to cool a 1300-MW (e) nuclear plant with an ammonia bottoming cycle system. A memorandum of understanding between EPRI and EDF provides for close cooperation and technical information exchange on the dry-cooling technology development under way in France and the United States. □



ties of ammonia in a utility plant environment is an important objective of the test program. In the chemical and fertilizer industries, quantities of as much as several thousand tons are routinely transported and as much as 40,000 tons is commonly stored in a single tank.

Most important, the phase-change system must satisfy appropriate safety and reliability requirements and must respond to the operational fluctuations of a power plant.

The test program consists of four categories of tests: passive, active, functional demonstration, and nonstandard condition tests. Passive tests measure the system's response to ambient condition variations. Active tests measure the response to controlled changes in specific operating variables and their effect on overall performance. Functional demonstration tests are used to observe system behavior during normal facility operation, including shutdown and startup, deluge cycles, load following, and loss of turbine generator load. Nonstandard condition tests show how the system recovers from possible, but unlikely, events that may occur during operation, such as plugging of heat exchanger fins, loss of fan power in the cooling tower, or loss of recirculation pump power.

The tests will yield data to produce equations that describe the system response to external changes in both steady-state and transient conditions. Diagnostic tests will lead to heat and mass balances for major components.

Early results from the test phase have been encouraging in their lack of surprises in terms of both the technology and the economic projections, according to John Bartz, manager of the EPRI ACT project. "The major components are operating about as expected, and we have demonstrated stable operation—an important step," says Bartz. "Before testing began there was some concern that the ammonia loop could develop a percolator effect [in which liquid ammonia flows unsteadily from the boiler, as does water in a coffee percolator] but we've seen none of that."

Six startup-shutdown cycles have been completed in shakedown tests so far; these tests confirm basic operating steadiness and controllability. When operated in an all-dry mode with the Curtiss-Wright heat exchangers, the system has already handled up to 80% of total design heat rejection capacity; tests at 100% load are in preparation. Initial tests show all phase-change loop pressures, temperatures, and flow rates holding steady during operation.

The early tests also show subcooling of the ammonia in the tower by about 10°F (6°C) below the design value (125°F, 51°C) as a result of the effect of fan blade pitch. If the subcooled ammonia were sent directly back to the condenser-reboiler, efficiency would be impaired because sensible heating would occur before reboiling could begin. A reheating hot well has proved effective in restoring the subcooled ammonia to saturation, bringing the temperature of the ammonia reentering the condenser-reboiler to within 0.5°F (0.3°C) of the vapor temperature leaving the reboiler. Another solution to subcooling that may be included in future designs would be redesigned controls that incorporate the degree of subcooling as an element of the control logic to modify the fan blade pitch.

Other observed effects in the early tests include greater-than-expected air flow rates through the cooling tower that result from the buoyancy of the air heated by the exchangers. The air buoyancy allowed the tower to run at about one-third its rated duty without setting the fan blades at positive pitch, indicating the benefit of designing the tower to take advantage of this effect. A procedure was established for venting noncondensible gases from the ammonia circuits (air and the hydrogen from the ammonia-metal interaction), but no noncondensibles have been observed.

Utility participation

To gain practical advice that will aid in the commercialization of the technology, the cosponsoring utilities serve as a project advisory committee with direct input to the testing schedule and preliminary results. The group currently consists of PG&E, Southern California Edison Co., Los Angeles Department of Water & Power, Salt River Project, and Canadian Electrical Association.

Under a memorandum of understanding for technical information exchange, EPRI is cooperating closely in the ACT project with Electricité de France (EDF), which is building a 20-MW (e) ammonia-based binary-cycle facility near Paris. The addition of a generating turbine on the ammonia loop provides added peak generating capacity, as well as improved overall efficiency and economics—making the ammonia loop cooling technique applicable not only in summer-peaking areas, such as most of the United States, but also in climates that experience winter-peaking conditions, such as France.

Prior experience in other industries and in laboratory and pilot-scale research demonstrated that the ammonia phase-change cooling system can be a thermodynamically efficient heat transfer process. Preliminary results from the ACT facility indicate such a system can be reliably and safely operated in a power plant setting. When testing is completed in 1984, the utility industry should have in hand the necessary data on which to base decisions to install advanced dry-cooling systems in cases where the cost of not using water for cooling is outweighed by its unavailability. ■

Further reading

J. A. Bartz and J. S. Maulbetsch. "Are Dry-Cooled Power Plants a Feasible Alternative?" *Mechanical Engineering*, Vol. 103, No. 10 (October 1981), pp. 34–41.

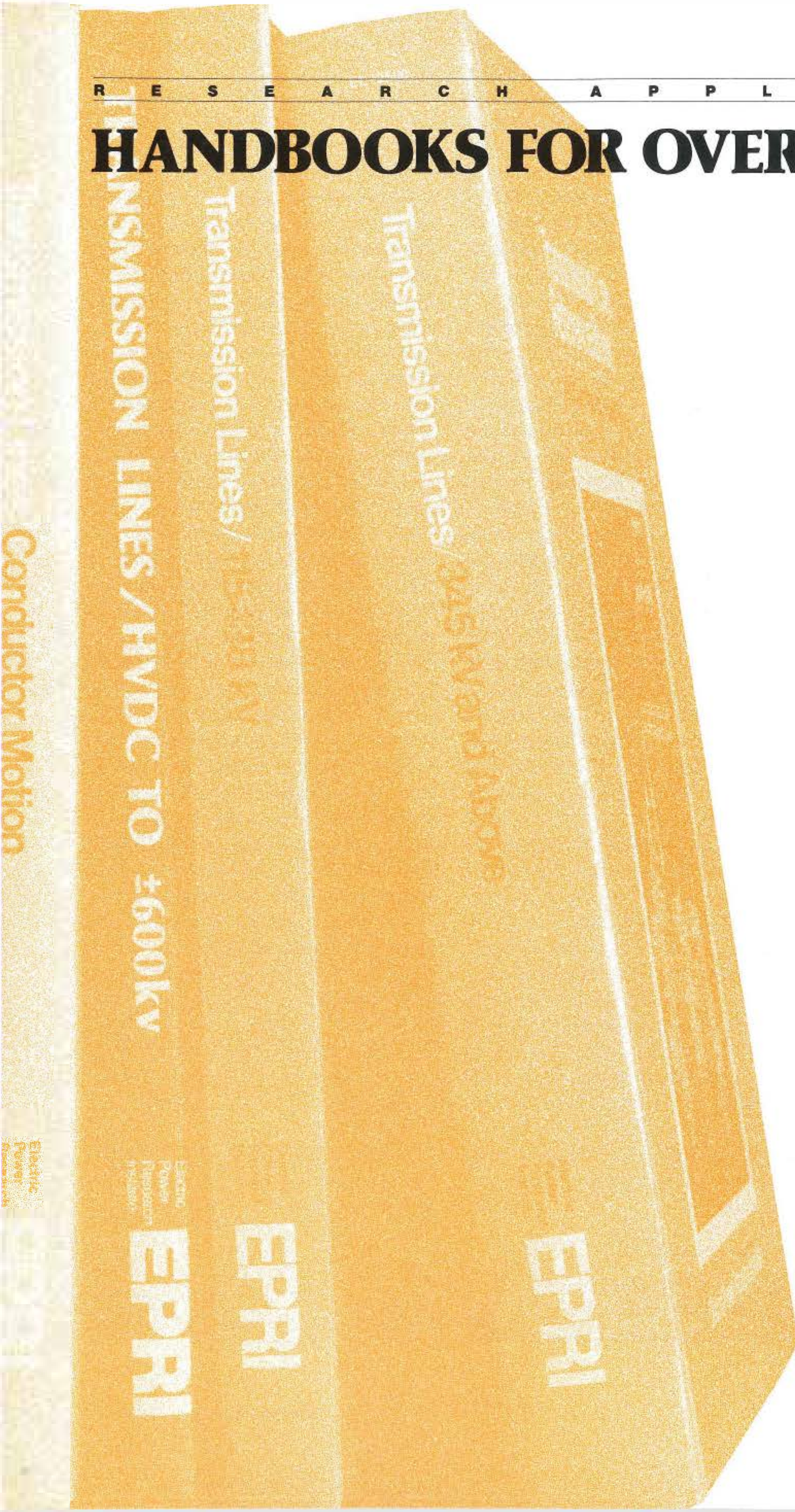
Advanced Concepts Test Facility—Measurements and Suggested Test Plan. Interim report for RP422-3, prepared by Battelle, Pacific Northwest Laboratories, September 1980. EPRI CS-1530.

Power Plant Waste Heat Rejection Using Dry-Cooling Towers. Summary report for RP422-2, prepared by Union Carbide Corp., February 1980. EPRI CS-1324-SY.

Nadine Lihach. "Water Water Everywhere, But . . ." *EPRI Journal*, Vol. 4, No. 8 (October 1979), pp. 6–13.

This article was written by Taylor Moore. Technical background information was provided by John Bartz and John Maulbetsch, Coal Combustion Systems Division.

HANDBOOKS FOR OVERHEAD LINES



Four EPRI-sponsored design guides provide a comprehensive reference for the transmission line engineer. Utility use of this series is resulting in substantial savings.

Today's transmission line engineer must make increasingly complex design decisions, with an eye toward meeting stringent electrical, mechanical, and environmental requirements while minimizing overall cost. Since 1975 EPRI's Electrical Systems Division has sponsored the development of a series of overhead transmission line reference books that provide comprehensive electrical design guidelines to help engineers make these decisions. The four volumes, often known by their vivid colors as well as their titles, now appear on many utility engineers' bookshelves. More important, they have proved highly useful off the bookshelf; several utilities have applied the guidelines with noteworthy success.

The red book, now in its second edition and the first book in the series, has the longest track record. Prepared by General Electric Co. for EPRI, *Transmission Line Reference Book, 345 kV and Above* (EL-2500) provides detailed coverage of the technology and backup data for EHV and UHV transmission lines up to 1500 kV. Drawing on state-of-the-art expertise gained in EPRI's multimillion-dollar Project UHV in Pittsfield, Massachusetts, the book not only is a valuable guide for U.S. line designers but also serves as a basic textbook in several universities and has been translated into Russian and Chinese. The 625-page second edition (1982) updates and expands on the 1975 edition, representing five additional years of research and new insight; a new summary chapter discusses transmission projects from the planning stage to the line-design stage for less experienced readers.

One satisfied user of the red book is the Bonneville Power Administration (BPA), which decided to construct an 1100-kV prototype line on the basis of supporting material in the EPRI design guide. BPA estimates that if it decides to proceed with the 1100-kV line rather than two double-circuit 500-kV lines, it will realize capital savings of $250,000 per mile (1980 $) and line loss savings of 500 kW per mile.

Although the red book recognizes the push toward higher voltages, the next volume in the series provides information on dc overhead lines, which are still relatively rare and not well documented. The 1976 *Transmission Line Reference Book, HVDC to ±600 kV* (EL-100-2), prepared by BPA, summarizes the results of a four-year R&D program to investigate and evaluate the voltage-dependent phenomena of dc overhead lines in the ±400 to ±600 kV range.

Of the few utilities so far involved in dc transmission, Minnesota Power & Light Co. and Cooperative Light & Power Administration/United Power Association are two that have depended on the green book in applying data on ionization, radio and television interference, corona loss, electric fields, and insulation coordination. As research progresses and as more utilities require information on dc lines, EPRI expects demand for an expanded second edition, now planned for around 1985.

The blue book in the series, prepared by Power Technologies, Inc., and published in 1978, has become highly useful to utilities venturing into the uncharted ground of compact line design. *Transmission Line Reference Book, 115–138-kV Compact Line Design* (EL-100-3) makes a major contribution in providing data not previously available on compacting and in mapping new design strategies for efficient use of transmission rights-of-way with minimal environmental impact.

The data and calculations in the blue book reflect experience with experimental 115- and 138-kV lines built in an EPRI-sponsored compact line project in Saratoga, New York. Most significantly, as several utilities have found in practice, the book documents the viability of reducing phase-to-phase spacings from 10–14 ft (3–4.2 m) to as little as 3 ft (0.9 m) without jeopardizing line performance. Utah Power & Light Co., for example, found that it could upgrade several 46-kV and 69-kV subtransmission circuits near Salt Lake City by using 6-ft (1.8-m) phase-to-phase spacing. The utility estimates that this compact line design reduced its line investment by $4500 per mile by enabling it to drop pole heights by 10–15 ft (3–4.5 m).

Otter Tail Power Co. in Minnesota and Puget Sound Power & Light Co. report similar successes, both pointing to the blue book as their major source. With their 41.6-kV lines becoming overloaded, Otter Tail engineers found that they could upgrade to more than twice the voltage (115 kV) by the simple modification of changing the insulators, leaving the lines as close together as before. The utility has installed trial lines, estimating that the new method costs only one-third as much as installing a new line. Similarly, PSP&L adopted the blue book method as its standard design on finding that it could save 10% by using the new design in a line near a golf course where esthetics was important.

Richard Kennon, program manager for Overhead Transmission Lines in the Electrical Systems Division and overseer of the reference books, characterizes the fourth book in the series as "an undiscovered treasure." Published in 1979, the orange *Transmission Line Reference Book, Wind-Induced Conductor Motion* (EL-100-4) is a slightly different breed from its companion volumes. Since not enough hard evidence is in on some of the issues raised by wind impact, the book is more a reference manual than an explicit design guide. However, it is the most comprehensive source of existing knowledge on the characteristics of wind-induced motion and on available protection schemes for line conductors and support systems. Prepared by Gilbert/Commonwealth, the book is the culmination of a three-year study of state-of-the-art expertise on conductor fatigue, aeolian vibration, conductor gallop, and wake-induced oscillation.

Taken as a series, the reference books provide a sophisticated library on the major electrical issues surrounding transmission line engineering. For individual engineers—who can obtain the books through EPRI's Research Reports Center—the series is a valuable front-line design tool. For the utilities that incorporate specific guidelines into new or modified transmission systems, the books provide well-documented support for new design directions that will pay off in dollar savings and high-level designs. ■

This article was written by Adrienne Harris Cordova, science writer. Background information was provided by Richard Kennon, Electrical Systems Division.

The White House Fellowship Program

Two leaders in the electric utility industry recall their participation in one of the most prestigious fellowship programs in the nation.

Each fall from 14 to 20 young adults are catapulted into the center of federal policymaking in Washington as White House Fellows. The goal is, in part, "to provide gifted and highly motivated young Americans with some firsthand experience in the processes of governing the nation and a sense of personal involvement in the leadership of the society," according to the President's Commission on White House Fellowships, which sets program policy. To accomplish this, White House Fellows spend a year serving as special assistants in a cabinet-level agency, the Executive Office of the President, or the Office of the Vice President. They meet frequently with leaders from all walks of life and travel domestically and abroad to learn more about national and international issues. The result is a year unlike any other in their lives.

Among those who have served as White House Fellows are two electric utility industry leaders, EPRI Vice President for Research and Development Richard Balzhiser and Edison Electric Institute Senior Vice President Douglas Bauer. Says Balzhiser, "I would guess that there aren't many Fellows whose lives have not been profoundly influenced, both professionally and in terms of their own thinking and appreciation for government—its limitations as well as its opportunities."

Both Balzhiser and Bauer served as Fellows in administrations facing unusual challenges. As a 1967–1968 Fellow, Balzhiser saw government in action during a turbulent period in the nation's history that included student protests against the Vietnam war and the aftermath of racial riots in Detroit and Los Angeles. Bauer, a 1972–1973 Fellow, saw an administration under severe attack as details of the Watergate scandal came to national attention. Nevertheless, both developed essentially timeless insights into government operations.

Balzhiser believes his close proximity to the upper echelons of government gave him a more accurate perspective. "I developed a tremendous respect for the quality of people, their commitment, and the sacrifices they made in serving government at that level," he comments. "I also learned to appreciate the constraints under which people operate. There simply are limitations in terms of how rapidly one can move, how quickly administrations can change direction."

For Bauer, the year meant significant changes in his views of government and policy development. "Public policy issues are forever going to be important to me," he explains. "I think the change is caused by the presence and the proximity of public policy concerns in your life here in Washington, particularly if you're drinking deeply of that cup. That drama is one that sticks with you forever." But regarding government itself, his close view meant a certain loss of idealism. "I entered into the Fellows year with a lot of romance about government. But in seeing government operate, I became convinced less of the genius of those who happened to be the government in 1972–1973 than of the wonderful genius of those in the eighteenth century who wrote our Constitution to limit the authority and power of government."

Developing Statesmen

What gave Balzhiser and Bauer the opportunity to serve as White House Fellows was a rare combination of professional achievement, leadership capability, and community commitment. President Lyndon Johnson established the program in 1964 on the recommendation of John Gardner, then president of Carnegie Corp., who wanted some of the nation's most promising achievers to develop an in-depth understanding of government. The purpose was twofold: to help develop statesmen of the caliber of those who led the American colonies in the late eighteenth century and to increase the accessibility of government to all citizens by providing Fellows with insights they could take back to their communities.

Bauer explains that Gardner was concerned about indications that only a very small percentage of the nation's most promising people had any interest in government. And he tied that idea to a comment that Alexis de Tocqueville made more than a century ago: that democracy could survive any malady at all but its citizens' indifference. "Gardner saw that in Jefferson and Monroe's time there was a normal commerce between the public and private sectors that helped to keep government *our* government rather than *that* government, and I think his purpose in the program was to try to re-create such accessibility."

The primary criteria considered during the fellowship selection process include the candidates' demonstrated and potential leadership capabilities, their professional achievements, and their degree of community involvement and commitment. Although the program has no age limitation, it is designed primarily for those in the early stages of their professional careers. The program also attempts to choose Fellows from all segments of society. The 18 classes that have completed the fellowship program so far include individuals from business, government, the arts, academia, and many other fields. "Clearly, excellence in your professional attainments is a primary factor," comments Balzhiser, "but just as important is some evidence of knowledge and interest in broader societal issues and concerns."

The competition for annual fellowship openings is intense, with only a handful of the 1000 to 2000 applicants selected. Those seeking fellowships first must submit a 15-page application outlining their qualifications. About 110 regional finalists are selected and interviewed by panels in 11 locations around the country. Those panels select about 33 finalists who are invited to Washington to be interviewed by the president's commission, which forwards its final choices to the president for approval.

Bauer and Balzhiser agree that the application procedure is an educational experience in itself. Bauer recalls, "You think about what the country is going through, the issues with which it is dealing, and about what are matters of public policy. That is probably a familiarization that goes beyond what you would normally be doing as a citizen."

Balzhiser adds, "The paperwork forces you to do a little bit of research on yourself, and the people who interview you are of national stature. At each step of the process I felt that the time and effort it had taken more than rewarded me for what I had put into it. Even while waiting to hear, I came to the conclusion that as much as I would like to be a Fellow, even if I wasn't selected I had grown tremendously and learned an enormous amount."

New Opportunities

Balzhiser applied for his White House Fellowship while an associate professor at the University of Michigan in Ann Arbor. He already had extensive experience in local government, having served as an Ann Arbor city councilman and as mayor pro tem, and he wanted to decide whether to make a greater commitment to public service or to continue with his professional endeavors. The fellowship program, from his perspective, offered him an excellent opportunity to develop a better understanding and appreciation of government, and this could help him make that decision.

After Balzhiser was awarded a fellowship and was assigned to the Department of Defense, he formed three specific goals: to learn more about the federal government's role in domestic unrest, to gain a better understanding of international programs and policies, and to learn as much as possible about advanced technology emanating from government programs. He has realized those goals, and more.

During his first six months as a Fellow, he was able to enhance his understanding of international affairs as a member of the Vietnam Task Force, which had been created by Robert MacNamara, then secretary of defense, to analyze United States involvement in Vietnam. While with the task force, Balzhiser wrote a paper on the justification for U.S. involvement in Vietnam, which became part of what was ultimately known as the Pentagon Papers.

He then plunged directly into federal policymaking on civil disturbances as assistant for the last half of his fellowship year to the under secretary of the army, who had been given principal responsi-

Bauer

Balzhiser

bility for coordinating DOD's involvement in domestic unrest.

Throughout the year, he also worked closely (primarily on an informal basis) with John Foster, the principal technical official at the Pentagon. Through his association with Foster and others at the Advanced Research Projects Agency, he gained many insights into government operations in the technical arena.

The high caliber of those in government is one of Balzhiser's most lasting impressions. "You come away with a much better understanding of what motivates people, of the competence of the people that surround the principals. You really work as a member of their close staff in most assignments so that you're integrated right into the functioning of the office," he emphasizes. "I became very close to the senior military people and to their principal aides and assistants, most of whom were on a fast track out of the military academies. I was tremendously impressed with the caliber of people who were in those assignments. They were really superb."

In terms of government process, Balzhiser says, "One of the things people talk about but that you don't fully appreciate until you get in the middle of it is what's meant by bureaucracy. You appreciate the constraints that operate on people at that level—the institutional barriers that exist, the political significance of events and actions; all of that becomes much, much more clearly understood." He explains, "People who have made a career of government are certainly dedicated and talented, but they are also many, and just the large number involved produces a great deal of inertia in the system. You develop a clear appreciation of what government can and cannot do."

The Fellows' educational program is an equally important part of the year. Usually two or three times a week they meet for discussions with leaders in all fields of endeavor, including business, government, the arts, and the media. In addition, they travel to other parts of the country to learn more about various issues and, in some years, travel abroad.

Balzhiser remembers that he and other Fellows attended more than 100 meetings with senior government officials, senators and congressmen, ambassadors, business leaders, and others. Among the meetings he recalls best were several with President Johnson, who candidly voiced his views and concerns about the war in Vietnam and other current issues. Although Balzhiser's group did not travel outside the United States, they did make domestic field trips. During a trip to New York City, the group met with numerous leaders, including the secretary general of the United Nations, Mayor John Lindsay, David Rockefeller, and members of the *New York Times* editorial staff.

Like Balzhiser, Bauer sought a White House Fellowship in order to learn more about government. He had just completed work on his PhD in engineering at Carnegie-Mellon University when he applied, and as he remembers, "I was increasingly persuaded that government at all levels, and the federal government specifically, affected the opportunities and also the burdens in our lives. I wanted to learn more about it."

When Bauer was awarded his White House Fellowship, he asked to be assigned to an agency dealing with topics in which he had no professional expertise. "I felt that if I went to work in a department in which I had a very obvious background, I'd just go to work, and it would start to be merely another job. But going to a department that I didn't know much about at all would be a tremendous learning experience."

Bauer was assigned to the Department of Transportation, where he worked for the secretary of transportation and became involved in many different projects and issues. But most important in his view was his involvement in energy-related activities that cut across the entire agency. "I was involved in air issues with the Federal Aviation Administration, highway issues with the Federal Highway Administration, and even some Coast Guard issues," he explains. "And I tried to bring to the department some understanding of the energy consequences of making or not making certain kinds of decisions—remember, this was before the oil embargo but at a time when people were starting to get interested in energy."

Throughout his stay at DOT, Bauer observed how government dealt with the issues confronting it. "I would look at assignments from the point of view of which ones would offer the greatest opportunity to learn something about government, about the bureaucracy, the interplay between the executive branch and Congress, and what occurs when presidential appointees make a decision and the bureaucracy actually has to carry it out," he explains. "This also meant seeing how the views and objectives of administrators with specific areas of responsibility would coalesce with the transportation secretary's objectives, which included prioritizing budgets and perfecting an enlightened balance across the whole national transportation system."

While working at DOT, Bauer also spent many hours participating in the educational portion of the fellowship program, an experience that convinced him that his fellowship year was the best of all. He recalls, "We had some remarkable opportunities in our year, not only in the people we were able to meet domestically—governors, mayors, and leading people from the media, the arts, and elsewhere—but also in our foreign travels. We traveled extensively in our year, and these were extraordinary, eye-opening experiences." Bauer's group was one of the first from the United States to visit the People's Republic of China, staying for about three weeks. The Fellows also visited the Soviet Union, Japan, Bulgaria, Poland, and East and West Germany.

Bauer is convinced that because of the intensity of the Fellows' year and the tremendous number of valuable experiences over a relatively short time, it is only later that a participant can evaluate its influence, can decide, in his words, "what, if anything, will have a permanent effect on your life."

Regarding one such effect, his intensified interest in public policy issues, Bauer says, "If you are living in some other city you organize your life around the essential things of your family and community and work. You probably keep in touch with the world through a local newspaper or perhaps even a national newspaper. But nothing sears into you the way it does when you're in Washington and exposed at the level you are as a White House Fellow to what is going on."

Bauer describes his exposure to government, however, as having "a curiously counterintuitive result." Among the key lessons learned was that "there are lots of things governments shouldn't try, even if they approach them with good intentions—things governments just don't do very well." He attributes this partially to the cumbersome nature of government but also to other factors. "One of the lasting impressions from being a Fellow," he says, "is how very big our country is and how dispersed are its sources of creativity. However bright are the people you bring into one city—let's call it Washington—there is no way that their creativity on various issues is as important as the creativity that is dispersed throughout our society. And there's no way that they can even read the problems as accurately as they're read on a dispersed basis throughout the country."

As a result of the program, Bauer also believes that he developed a healthy skepticism about government, making him, as author John le Carré described himself in a recent interview, a disgusted patriot. "That's a wonderful junction of words," says Bauer. "A 'disgusted patriot' cares—it matters what happens to the country, what it stands for, what occurs in public policy; but a 'disgusted patriot' also recognizes that government has all the warts of any human institution, and the people in it can't claim any special human capabilities merely because they are high officials. I think the Fellows program teaches you that. You will be wined and dined by the high and the mighty, and you will get it all out of your system, and I think it probably creates some 'disgusted patriots.'"

Using the Experience

The year went extremely quickly for Bauer and Balzhiser. Both discovered, however, that they were to spend much more time later in Washington in important government leadership positions, primarily as a result of their involvement in the fellowship program.

Balzhiser first returned to his home in Ann Arbor. He felt a commitment to return to the university, which had granted him a year's sabbatical leave, and also to pass along his knowledge through public service, in line with the program's intent. He found when he returned that a certain amount of reorientation was necessary. "After being in Washington, you understand what they mean by Potomac fever," he says. "Washington is unique. The axis of the world really goes through Washington and the topic of conversation—whether at a lunch table, a cocktail party, or wherever—is related to national and international issues. It's a charged environment and very stimulating."

Balzhiser did return to Washington, however, in 1971 as assistant director of the Office of Science and Technology, with responsibilities in energy, environmental, and natural resource areas; this move was the result of contacts he made during his fellowship year. Two years later, after gaining extensive experience in dealing with energy issues, he decided to join EPRI. "I had become deeply involved in the energy issues of that time and was convinced they were going to be with us for some time. The creation of EPRI provided me with an opportunity to have significant impact in an area of tremendous international and national concern, so I felt this was just an ideal opportunity."

Bauer remained in Washington, holding several key energy-related positions in the federal government before moving into the private sector. Shortly after he completed his fellowship year, he joined the Department of Interior's Office of Energy Conservation to set up energy conservation research and development programs. He then joined the newly formed Federal Energy Administration's Office of Energy Conservation and, among other things, initiated the FEA load management and time-of-use rate demonstration projects. From 1976 to 1977, he directed a nuclear research division at the Energy Research and Development Administration, and from 1977 to 1978 was assistant administrator in charge of utility programs at DOE's Economic Regulatory Administration.

Bauer then decided to leave government service, first joining the American Electric Power Co., Inc., as executive assistant to the vice chairman and then to the president, before joining EEI in 1979 as senior vice president for economics and finance.

Since then he has earned a law degree from Georgetown University and has been admitted to the bar of the District of Columbia. That pursuit was motivated, in part, by the Fellows year experience, which demonstrated the importance of multidisciplinary perspectives in affecting public policy.

Bauer and Balzhiser have kept in touch with many of the people in their fellowship classes, and Bauer notes that many have gone on to important positions in their fields. "I'm terribly impressed with the subsequent careers of a number of the Fellows," he says. "A number of people who went through in my year are now ranking officers in the military. Others have done very well in the corporate world, have gone back to academia, or are physicians. And since they are such leading members of their communities, I feel better that they had this kind of exposure to government early in their lifetimes."

Bauer, Balzhiser, and other Fellows have the opportunity to return to Washington each year for briefings on current issues facing the nation. Typically, those meetings include discussions with senior government officials, business leaders, ambassadors, and other leaders. "You get an opportunity to go back and recharge your batteries—update your understanding—on important national and international issues," comments Balzhiser. "It allows you to get the point of view of some of the principals and again benefit from questioning many enlightened people."

Bauer believes that he and other former Fellows feel a special responsibility to serve the program. For example, he takes time each year to review some of the applications submitted by prospective Fellows. Balzhiser encourages others to apply for the fellowship program, and believes businesses should encourage their employees. "I think employers must do so, realizing that the persons may or may not return to them. Even if they don't, I think the business and the individual will benefit immensely in the long run."

Those who wish further information on the White House Fellowship Program should contact President's Commission on White House Fellowships, 712 Jackson Place, N.W., Washington, D.C. 20503. Applications will be available in August for the 1983–1984 fellowship. ■

This article was written by Doris Newcomb, a freelance writer who specializes in energy issues.

Promising Results From Synfuel Process

Reduced hydrogen consumption is the key to higher efficiency in a new liquefaction technique.

Should early results be sustained, a major technological step will have been achieved toward economically competitive coal-derived synthetic fuels. Recent tests at an Alabama pilot plant demonstrated substantial progress in developing a more efficient and potentially less costly technique for converting coal into a clean liquid fuel substitute for petroleum or natural gas.

The process, known as integrated two-stage liquefaction, is one of the new generation of coal-to-liquid technologies under study by EPRI and DOE. Testing is being conducted at EPRI's Advanced Coal Liquefaction Research and Development Facility in Wilsonville, Alabama. Over the past 10 years, EPRI and DOE have provided more than $60 million for evaluation and testing at the facility. The project is managed by Southern Company Services, Inc., the engineering and research subsidiary of The Southern Company, and the plant is operated by Catalytic, Inc.

Hydrogen is a key ingredient needed to convert coal into synthetic fuel. The amount of hydrogen required to change a given quantity of coal to high-quality oil is a measure of the production efficiency, and hence a determining factor in the cost of the fuel oil. In recent tests of the two-stage process at the Wilsonville facility, engineers were able to obtain nearly 15 pounds of high-grade distillate fuel for every pound of hydrogen consumed in the process. This represents substantial improvement over the current generation of coal liquefaction processes.

The test results, while extremely promising, have been achieved on a small scale of about 3 t/d, researchers at the center caution. Full-scale commercial plants are expected to use on the order of 20,000 t/d of coal. Nevertheless, EPRI Program Manager Howard Lebowitz said, "The recent results would have been considered impossible a few years ago. It was previously believed that high hydrogen consumption could not be avoided when producing clean distillate fuels. This improvement should lead to a significant reduction in the cost of making these fuels."

In two-stage liquefaction, coal is first dissolved under heat and pressure into a heavy, viscous oil. Then, after ash and other impurities are removed in an intermediate step, the oil is combined with hydrogen in a second vessel to produce a lighter, more easily refined product. A catalyst added in the second stage aids the chemical reaction with hydrogen.

Separating the process into two stages rather than one keeps the hydrogen consumption to a minimum. Mineral and heavy organic compounds in the coal are removed between stages by using Kerr-McGee Corp.'s critical solvent de-ashing unit.

Current tests at Wilsonville are concentrating on Illinois bituminous coal, considered typical of much of the high-sulfur coal found in the midwestern and eastern United States. ■

Culler Keynotes 10th ET Conference

The Energy Technology Conference and Exposition celebrated its tenth year February 28–March 2 in Washington, D.C., with roughly 5500 in attendance. EPRI President Floyd Culler recalled in the keynote address that 1983 also marks the tenth year since the OPEC oil embargo and the formation of EPRI.

In his speech, Culler outlined the changes that occurred in the past decade, including the turbulence of oil prices, the effect of energy supply and demand on the economy, and the increasing emphasis on energy efficiency and conservation. He is optimistic about the future of the country's economy, noting that over the past 10 years, the demand for electric power has closely followed the nation's gross national product. Culler discussed new energy technologies that will have a significant effect on the energy future, commenting, "As we have done in previous times of difficulty, we will turn to new technology to restore our economy and our faith in ourselves."

Other EPRI officials leading various conference sessions included John Dougherty, director, Electrical Systems Division; Fritz Kalhammer, director, Energy Management and Utilization Division; and Kurt Yeager, director, Coal Combustion Systems Division. Richard Rudman, director, EPRI Information Services Group, chaired the Founders Luncheon, which featured an address by Congressman John Dingell (D-Michigan), chairman of the House Committee on Energy and Commerce.

EPRI was among 149 organizations with exhibits at the conference. On display at the EPRI booth were models representing the 20-MW (e) TVA–EPRI-sponsored atmospheric fluidized-bed combustion pilot plant in Paducah, Kentucky; the Arapahoe Test Facility in Denver, Colorado; the Scorpion advanced cable plow; and a 50-kWh zinc chloride load-leveling battery. The on-line Electric Power Database was demonstrated at the booth, with individually tailored information searches performed for those attendees interested in learning more about electric utility R&D. ■

Board Elects New Chairman

New officers and two additions to EPRI's Board of Directors were elected during the annual meeting of members and the Board in Washington, D.C., in April.

The Board of Directors elected A. J. Pfister, general manager of the Salt River Project in Phoenix, Arizona, as chairman; Arthur Hauspurg, chairman and president of Consolidated Edison Co. of New York, Inc., was chosen as vice chairman for the coming year. Hauspurg had been reelected to a four-year term on the Board the preceding day during the yearly meeting of EPRI member utilities.

Two new directors named to four-year terms were John D. Selby, chairman of the board of Consumers Power Co. of Jackson, Michigan, and Richard F. Walker, president of Public Service Co. of Colorado in Denver.

Barton W. Shackleford, president of Pacific Gas and Electric Co. in San Francisco, was named to a second four-year term.

Chairman Pfister has been a member of the EPRI Board for nearly two years. Prior to joining the Salt River Project in 1970 as special assistant to the associate general manager for power, Pfister spent 11 years as an attorney. He was named general manager of the Salt River Project, a public electric and water utility serving central Arizona, in July 1976. Pfister is a past president of the American Public Power Association and currently serves on the boards of the Western States Water and Power Consumers conference, the Western Energy Supply and Transmission Associates, and the Atomic Industrial Forum.

Hauspurg began his career with Consolidated Edison in 1969 as a vice president; he was named a senior vice president in 1973 and was appointed executive vice president and chief operating officer in mid 1975. He became president in October 1975 and has been chairman since September 1982.

Shackleford became president of PG&E in June 1979; he has been with the northern California utility since 1946. After serving in a number of engineering positions, he became vice president for planning and research in 1971, senior vice president in 1976, and executive vice president and director of PG&E in 1977.

Selby joined Consumers Power in April 1975 as president and member of the board. Three years later he was named chief executive officer and was elected chairman in October 1979. Selby previously spent 28 years with General Electric Co., where he served in various executive capacities. He is also a director of the Edison Electric Institute (EEI) and the Atomic Industrial Forum.

Walker has been president and chief operating officer of Public Service Co. of Colorado since September 1976. He was named chief executive officer in 1978. His utility industry career began in 1949, when he joined Public Service as an assistant engineer. He is a member of the board of directors and of the executive committee of EEI. ■

EPRI Honored for Energy R&D

The National Energy Resources Organization (NERO) has honored EPRI for its work by presenting the Institute with its 1982 Energy Research and Development Award, given each year to individuals and institutions that have made significant contributions to advancing energy technology.

NERO officials said that EPRI was honored because it had "maintained a heavy investment in research and development across the entire spectrum of energy technology during a period when federal and private funds have diminished."

Founded in 1975, the Washington, D.C.–based NERO provides a forum for business, industrial, and government leaders to meet and exchange ideas on the development, supply, and use of energy. It also works to publicize advances in energy technology. Other institutions that have won the award in previous years include the Gas Research Institute in 1981, Exxon Research and Engineering Co. in 1979, and Hydrocarbon Research, Inc., in 1978.

In accepting the 1982 award at NERO's annual banquet, EPRI President Floyd Culler said, "We are very pleased to receive this recognition of the work of our staff and many contractors. It is equally a compliment to the electric utilities for supporting the research and development so necessary to our society." He added, "Each year, several individuals who work for EPRI have been the recipients of prizes and awards for outstanding work and contributions to science and technology, and individual projects have been recognized periodically by national and international organizations for special merit, but this is the first time the Institute itself has been chosen for national recognition." ■

CALENDAR

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

MAY

10–12
Face Seals for Nuclear Main Coolant Pumps
St. Charles, Illinois
Contact: Floyd Gelhaus (415) 855-2024

11–13
8th Annual Contractors' Conference on Coal Liquefaction
Palo Alto, California
Contact: Suzette Gordon (415) 855-2491

16–20
Fault Tree and Event Tree Systems Analysis Methods
Chicago, Illinois
Contact: David Worledge (415) 855-2342

17–20
Annual Review of Demand and Conservation Research
Arlington, Virginia
Contact: Ahmad Faruqui (415) 855-2630

24–26
Seminar: Transmission Line Grounding
Palo Alto, California
Contact: John Dunlap (415) 855-2305

JUNE

1–3
Symposium: Condenser Macrofouling Control Methods
Hyannis, Massachusetts
Contact: Isidro Diaz-Tous (415) 855-2826

3
Power Plant Plume Studies
Washington, D.C.
Contact: Richard Bratcher (415) 855-2736

6–10
Seminar: Applications of Decision Analysis for Fuel Planning
Kansas City, Missouri
Contact: Stephen Chapel (415) 855-2608

6–10
Seminar: High-Voltage Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

7–8
Seminar: Mutual Design of Overhead Transmission Lines and Gas Pipelines
Schaumburg, Illinois
Contact: John Dunlap (415) 855-2305

7–9
Symposium: Power Plant Condenser Technology
Orlando, Florida
Contact: Isidro Diaz-Tous (415) 855-2826

14
Load Forecasting for Small Electric Systems
Minneapolis, Minnesota
Contact: Joseph Wharton (415) 855-2924

16
Load Forecasting for Small Electric Systems
Atlanta, Georgia
Contact: Joseph Wharton (415) 855-2924

21
Load Forecasting for Small Electric Systems
Kansas City, Missouri
Contact: Joseph Wharton (415) 855-2924

21–23
Symposium: Load Research
Chicago, Illinois
Contact: E. Beardsworth (415) 855-2740

23
Load Forecasting for Small Electric Systems
Washington, D.C.
Contact: Joseph Wharton (415) 855-2924

JULY

12–15
Annual Review of Demand and Conservation Research
Denver, Colorado
Contact: John Chamberlin (415) 855-2750

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

EVALUATION OF THE TEXACO GASIFIER

EPRI has an ongoing interest in projects involving the Texaco coal gasification process (TCGP). The best-known is the Cool Water project, a commercial-size facility that will integrate a 1000-t/d Texaco gasifier with a dedicated combined-cycle power plant (EPRI Journal, *September 1982, pp. 18–25). In support of Cool Water, EPRI has sponsored tests at Texaco's Montebello Research Laboratory, which houses a 15-t/d gasifier (RP985), and at Ruhrkohle-Ruhrchemie's plant in Oberhausen, West Germany, which has a 165-t/d gasifier (RP1799). The primary objectives of these preliminary tests were to acquire gasifier performance data and to evaluate the scale-up considerations for the 1000-t/d Cool Water gasifier.*

A major advantage of the TCGP is its relative simplicity; consequently, performance can be easily correlated. The major independent operating variables of the Texaco gasifier, which is fed by oxygen and a coal-water slurry, are the slurry feed rate and oxygen-to-slurry ratio. The coal-water slurry is held at the highest pumpable concentration for maximum thermodynamic efficiency. The oxygen-to-slurry ratio is generally expressed as the atomic oxygen-to-carbon ratio (O/C ratio) to reduce differences in performance curves for varying slurry concentrations and different coals.

An ideal performance correlation would relate the independent operating variables (O/C ratio and slurry feed rate) to key dependent variables with the following characteristics.

- Strong economic and physical significance
- Ease of measurement or calculation
- Significant variation over the feasible operating range
- An orderly relationship to the operating parameters

Carbon conversion meets these criteria, as does gasifier temperature (Figure 1). Carbon conversion is determined by a carbon balance around the gasifier. Unfortunately, accurate measurement of temperature is impossible in the hostile environment of the gasifier, so it is usually calculated from the heat and material balances. Temperatures calculated in this way are average temperatures rather than peak temperatures.

Operating range

At high O/C ratios, a small increase in O/C ratio results in a relatively large increase in gasifier temperature (Figure 1). This temperature increase occurs because gasification reactions are starved (i.e., less carbon is available for gasification). Consequently, the dominant reactions at higher O/C ratios are the very exothermic combustion reactions that use the incremental oxygen and the syngas. This combustion of syngas and pure oxygen is not only thermodynamically undesirable but the resultant higher temperature accelerates refractory wear. Refractory wear rate establishes the maximum allowable operating temperature.

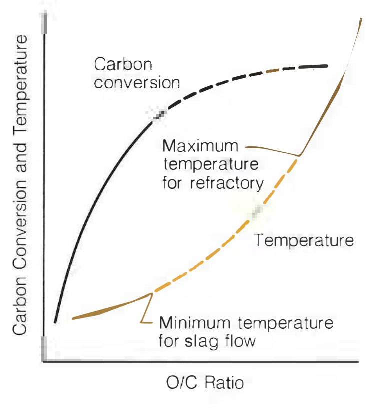


Figure 1 Relationships between carbon conversion, temperature, and O/C ratio. The allowable operating range (dashed) lies between the temperature at which slag flows freely and the temperature at which refractory wear is unacceptably high.

The maximum allowable operating temperature is not necessarily constant under all conditions. For example, because some slags are more aggressive than others at the same temperature, the maximum allowable operating temperature may be coal-specific. It may also be load-specific because gasifier hydrodynamics probably change with load, thereby influencing the unmeasurable and undeterminable peak temperatures.

At the other extreme, low O/C ratios result in low carbon conversion, inefficient coal use, and a larger volume of solid waste for disposal. Low O/C ratios also result in low average temperatures, and at some point, the slag will no longer flow freely. Operational problems result. The minimum operating temperature allowed by slag flow properties is a function of the ash composition.

Figure 1 illustrates the gasifier operating range determined by the minimum operating temperature allowed by slag flow and the maximum operating temperature allowed by refractory wear. When the operating range is unacceptable, a number of tactics are available. For example, if a particularly aggressive slag dictates that a low operating temperature be maintained (low carbon conversion), recycling unconverted carbon to slurry preparation can provide relief.

In addition to coal and ash composition, a number of design variables, such as feed temperature and gasifier and burner geometry, influence the performance curves. Understanding these variables is critical for carrying out a successful size scale-up. Researchers observed and analyzed scale-up effects in EPRI's comparative runs on the 15- and 165-t/d gasifiers and obtained valuable information for the Cool Water design.

Performance trends and EPRI test results

Test results at Montebello and Oberhausen have shown a consistent trend toward better gasifier performance at high load, as indicated by greater carbon conversion and lower temperatures at each O/C ratio. The low load performance deterioration was more significant in the larger gasifier at Oberhausen. Moreover, the EPRI test results also indicated that overall performance of the smaller gasifier was generally superior with the particular burner designs used.

These findings make clear that basic design changes are necessary for a scaled-up gasifier to maintain high performance. The EPRI tests and recent information obtained through RP2093 confirm that the know-how is available to successfully make those changes for the 15-t/d to 165-t/d scale-up. Thus, further success in the sixfold scale-up to the Cool Water size (1000 t/d) is also likely.

Figure 2 illustrates EPRI test results as the incremental heat rate of a hypothetical gasification–combined-cycle power plant, an approach that helps highlight economic trends. The arbitrarily selected zero incremental heat rate is based on operating conditions during test periods in which Oberhausen researchers collected environmental data.

Heat and material balances, using representative carbon conversion versus O/C ratio curves generated from the test data, determine the curves in Figure 2. The calculations assume typical constant coal composition (Illinois No. 6 coal) and slurry concentration but do not incorporate data for recycling unconverted carbon to the gasifiers because the EPRI tests did not include recycling. The dashed curve segments reflect performance at apparently excessive operating temperatures for the refractory. (Note: These curves were not necessarily generated at hydrodynamically or geometrically similar gasifier conditions.)

Figure 2 Changes in heat rate across the operating range of a hypothetical gasification-combined-cycle plant. Curves reflect data from EPRI tests on Illinois No. 6 coal at Oberhausen (color) and Montebello (black). Dashed portions of curves indicate operation at excessive temperatures.

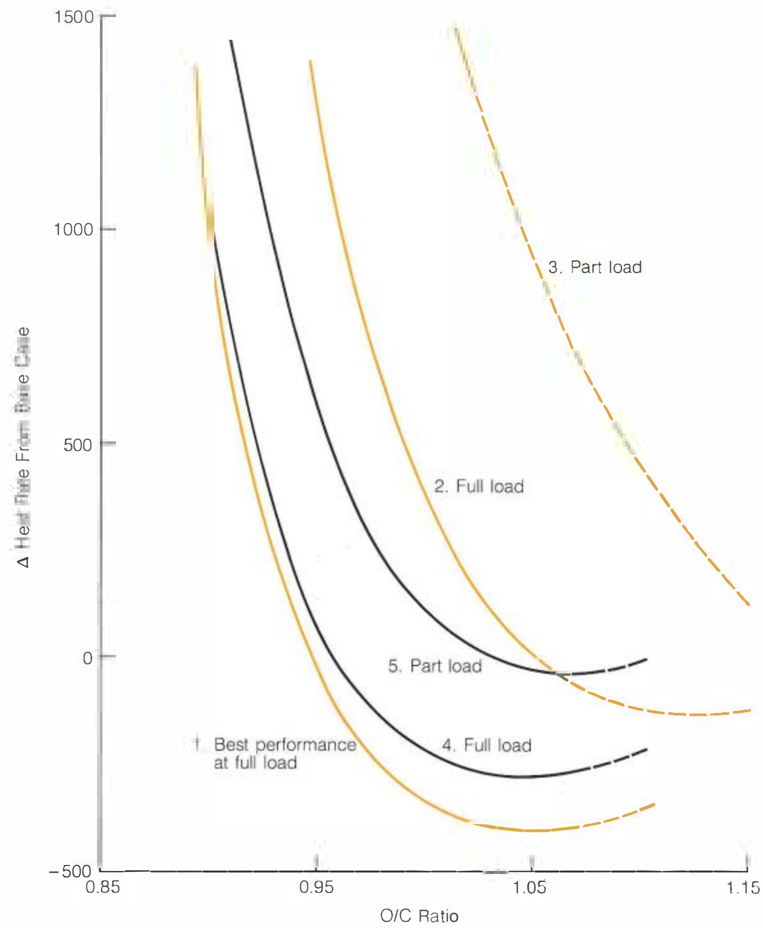


Figure 2 thus leads to three important conclusions. First, curves 1 and 4 show that the 165-t/d gasifier can be made to perform as well as the 15-t/d gasifier, given the appropriate conditions.

Second, curves 1, 4, and 5 all reflect very good performance, thereby providing a safety margin for operation. A plant with any of these three operating curves could hold the gasifier temperature well below the temperature at which the refractory is at risk with no penalty to plant heat rate. (Curve 2 is marginal in this regard, and curve 3 reflects relatively poor operational characteristics.)

Carbon recycling would dramatically reduce the slope of the left side of all curves in Figure 2, but recycling would be unnecessary if the plant operated according to curves 1, 4, or 5. Plant operators would probably consider carbon recycling in a plant with curve-2 operating characteristics and would almost certainly find it justified if they expected operation according to curve 3 (a turndown condition). On the basis of recent burner developments successfully tested at Oberhausen, Cool Water is expected to perform according to curves 1, 4, and 5. However, the facility contains a carbon recycling system as a contingency.

A third conclusion is that operation at turndown adversely affects plant performance at the EPRI test conditions. (Compare curves 4 and 5 for Montebello and curves 2 and 3 for Oberhausen.) Additional burner improvements developed and tested at Oberhausen have shown that this low load performance deterioration can be substantially reduced or completely eliminated. Thus, this improved burner design offers an attractive alternative to carbon recycling if full load performance characteristics are (marginally) acceptable but extensive operation is likely at turndown.

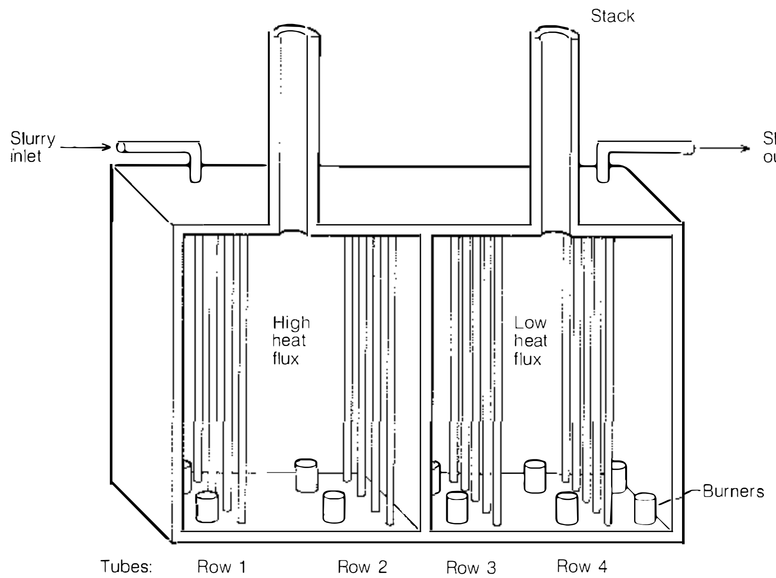
The curves in Figure 2 are coal-specific and plant-specific. The following variables most strongly influence these curves.

- Dry coal properties
- Ash/slag properties

- Refractory type
- Coal slurrying characteristics
- Gasifier/burner design
- Carbon recycling system
- Power cycle configuration
- Waste heat recovery system configuration

The Montebello and Oberhausen tests have produced extensive information on all these aspects of the Texaco coal gasification process. EPRI's support of the Cool Water project reflects its confidence in these results. *Project Manager: John McDaniel*

Figure 3 Cross section of two-cell furnace. The firing box of the slurry preheat furnace was divided into two individually fired zones. This modification allowed the heater to operate at lower tube metal temperatures at the slurry outlet.



EDS PROCESS DEMONSTRATION

The Exxon Donor Solvent (EDS) process development has been an integrated research and engineering program undertaken by Exxon Research and Engineering Co. (ER&E) to bring the EDS coal liquefaction process to commercial readiness. The $340.8 million effort was jointly funded by DOE and private industry participants: Exxon Co., USA; EPRI; Japan Coal Liquefaction Development Co.; Phillips Coal Co.; Anaconda Minerals Co.; Ruhrkohle (West Germany); and ENI (Italy). The operation of the 250-t/d EDS coal liquefaction pilot plant (ECLP) at Baytown, Texas, provided the critical data and operating experience necessary to design a commercial-size plant.

The EDS process was demonstrated at ECLP on three U.S. coals that encompass a wide range of coal ranks: Illinois No. 6 bituminous coal from the Monterey mine, Wyoming subbituminous coal from the Wyodak mine, and Texas lignite from the Martin Lake mine. Operations began on June 24, 1980, and terminated on August 20, 1982; a summary is given in Table 1. With the exception of the first operation, which was conducted in the once-through mode, ECLP was operated in the bottoms recycle mode at liquefaction conditions of increased severity. This was a modification of the original version of the process and was based on EPRI's suggestions.

The data from ECLP proved to be crucial in preparing for commercialization. In addition to the confirmation of the suitability of key equipment and hardware, three major process issues, which surfaced during the first coal operation, had to be resolved at ECLP: furnace coking, solvent quality maintenance, and differences in coal conversion and product yields obtained at ECLP and smaller pilot units.

Table 1
SUMMARY OF ECLP OPERATION

Coal	Operation on Coal (hours)	Longest Continuous Run (hours)
Illinois No. 6 bituminous (once-through)	2658	856
Illinois No. 6 bituminous (bottoms recycle)	2192	1031
Wyoming subbituminous (bottoms recycle)	2754	1389
Texas lignite (bottoms recycle)	1843	925
Total	9447	

Slurry preheater coking

Incidents of localized rapid slurry preheater coking were observed during the Illinois coal once-through operation in early 1981. The coking incidents continued during the first Wyoming coal operation with bottoms recycle at high-severity liquefaction conditions. Data correlation indicated that furnace coking at ECLP was affected by six variables: slurry film temperature, slurry solids concentration, hydrogen treat gas rate, solvent boiling range, solvent donor hydrogen content, and solvent saturates content.

The slurry film temperature was the one heater-related parameter influencing coking. The existing furnace was therefore modified to contain two cells: the inlet low-temperature cell operating at high heat flux, and the outlet high-temperature cell operating at low heat flux (Figure 3). The modified furnace was first used in the third coal operation, which began in late November 1981. The operation was conducted with Illinois No. 6 coal and bottoms recycle at high-severity liquefaction conditions. During the three months of operation with Illinois No. 6 coal, no hot spots or coke formation was detected in the modified slurry furnace. The slurry film temperature at coil outlet was reduced by 45°F (25°C) at equal slurry coil outlet temperatures.

The tube metal temperature again slightly increased during the fourth coal operation, which began early in March 1982. The operation was conducted with Wyoming coal and bottoms recycle at high-severity liquefaction conditions. Prior to commencing the last coal operation with Texas lignite, the two-cell heater was therefore further modified by reducing the diameter of the outlet coil tubes. This modification further reduced the slurry film temperature; no tube metal temperature increase was observed during the three months of operation with lignite.

Solvent quality maintenance

Concomitant with the slurry heater modification effort directed toward reducing the slurry film temperature, corrective measures were taken to improve the solvent quality maintenance. It was believed that a poor-quality solvent can significantly affect heater coking because of the enhanced asphaltene and preasphaltene precipitation, increased solvent vaporization, and reduced coal dissolution capability of the solvent.

The quality of the solvent was improved by several operating changes made in the solvent hydrotreating unit and the liquefaction-distillation units: the space velocity, hydrogen partial pressure, and reaction temperature in the solvent hydrotreating unit were adequately changed; the liquefaction temperature was increased; hydrogenated vacuum gas oil was incorporated into the solvent blend; the removal of light boiling saturate hydrocarbon was improved by distillation; and both the donatable hydrogen and the saturates content of the solvent were closely monitored by mass spectrometer analysis.

Typical solvent characteristics for the various coal operations are presented in Table 2. The implementation of the above-mentioned measures significantly improved the solvent characteristics.

▫ The donatable hydrogen, which is a measure of hydrogen that can be donated to coal, was improved.

▫ The saturate hydrocarbon content, which can trigger slurry furnace coking by asphaltene/preasphaltene precipitation, was significantly reduced.

▫ The solvent's specific gravity increased and its content of light hydrocarbons boiling below 600°F (315°C) decreased, resulting in a heavier solvent.

The heavier solvent has both reduced solvent vaporization and improved coal dissolution properties.

Table 2
TYPICAL SOLVENT QUALITY
(bottoms recycle operations)

Solvent Property	Wyoming Coal[1]	Illinois Coal[2]	Wyoming Coal[3]
Donatable hydrogen	Poor–Fair	Good–Very Good	Good–Very Good
Saturates (wt%)	28–34	18–24	19–24
Specific gravity	0.93–0.96	0.98–1.00	0.95–0.98
Light hydrocarbon content boiling below 600°F (liq vol%)	70–80	55–70	50–70

[1]July–October 1981.
[2]November 1981–March 1982.
[3]March–April 1982.

Coal conversion and product yields

Coal conversion and product yields achieved at ECLP were lower than those obtained in the smaller pilot units at equivalent nominal residence times. Radioactive tracer studies were initiated in an effort to clarify the differences in coal conversion. These studies have established the actual liquid residence time in ECLP and smaller pilot units.

It was also established that the degree of reactor backmixing is an important scale-up factor. In the case of Wyodak coal and Texas lignite, a conversion debit was also attributed to coal oxidation during the drying operation.

Based on this information, ER&E believes that it will now be able to predict coal conversion and product yields from results obtained in smaller pilot units sufficiently well for scale-up to commercial-size plants. It is expected, however, that the continuing reactor modeling effort will further improve the predictive tools and reduce the design conservatism.

Licensing availability

Following the completion of the two-year demonstration program in ECLP, ER&E concluded that it had enough data and know-how to design a commercial-size EDS coal liquefaction plant for the three coals tested at ECLP. ER&E decided to proceed with ECLP dismantling immediately after the final plant inspection and destructive testing of critical equipment. ER&E considers that the predictive tools developed within the R&D program, together with the operation of the small-scale pilot units of less than 1 t/d (which will be mothballed beyond the life of ECLP), are sufficient to provide the coal-specific data required to design a commercial-size EDS liquefaction plant for other applicable coals not tested in ECLP. *Project Manager: Nandor H. Hertz*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

COAL–CLEANING CONTROL SYSTEMS

Because coal is a fuel of highly variable quality, many coal producers have to clean their coal in some way to meet electric utility specifications. But cleaning plants are generally manually controlled and are not well instrumented. Better instrumentation and automated control can produce higher yields of marketable coal, less variability in coal quality, and labor savings. The rate of return on capital investment in improved instrumentation is likely to increase as coal prices rise, cleaning plants become larger and more complex, and instruments and control equipment become more sophisticated. EPRI has recently completed an investigation of control instrumentation under RP1338 and is continuing work in this area under RP1400. Current work is being carried out at EPRI's Coal Cleaning Test Facility at Homer City, Pennsylvania.

In 1981, 597 million short tons of coal were burned to generate 52% of the electricity consumed in the United States. Although actual statistics are not available on how much of this coal is physically cleaned, a reasonable estimate of coal currently being cleaned for electric utility use is approximately 25%, or about 150 million tons. At $32/t, an average 1% improvement in yield would provide nearly $50 million more of clean coal annually. Improvements in yields of at least 1% are generally achievable by simple, well-tuned automatic control systems.

The instrumentation in U.S. coal-cleaning plants has tended to be rudimentary compared with that in allied industries, such as mineral processing. Coal-cleaning plant operations have also typically been manually controlled, because in the past low coal prices have stifled economic incentives to invest in automated equipment. However, coal prices have risen in recent years in response to rising prices of competing fuels, creating incentives to improve cleaning plant operations. Automatic controls can bring about such improvements by serving four basic functions.

First, automatic control systems can start plant equipment up or shut it down without human intervention. Second, automatic control systems can adjust the rate at which processes occur. Third, control systems can lock equipment to prevent process upsets or dangerous conditions. Fourth, automatic systems can produce data logs for recordkeeping.

Automatic control systems may or may not require digital computers. However, computers are becoming increasingly common because they perform the control functions better than other systems and their costs are competitive.

Automated control systems offer the same advantages to coal cleaning as they do to other industrial processes. They improve product recovery (combustible coal) without reducing product quality. Automatic systems control product quality within tighter limits than can human operators. Such systems can reduce labor costs by replacing operators, a benefit likely to be realized only by large, well-instrumented coal-cleaning plants that operate three shifts a day.

A coal-cleaning plant can realize these advantages only when it is appropriately staffed. Plant personnel need expertise in coal-cleaning engineering, instrument maintenance, and automated control operation. Unfortunately, there are few people skilled in these fields today, and their continued scarcity could be a serious limit to automation of coal-cleaning plants in the United States.

The automation of the coal-cleaning industry in the United Kingdom is probably more advanced than in any other country. The U.K. experiences with such systems have been generally good, and the industry is continuing to build new installations. Computer systems have been installed in at least five plants in the United Kingdom; there are two in the United States. Advanced computer-based control systems have also been installed in West Germany and Australia.

An increasing number of coal-cleaning plant operators around the world are realizing the economic benefits of control system automation and sophisticated instrumentation. It is important that U.S. coal-cleaning plant operators also emphasize evaluation of the technical and economic aspects of different control systems for their plants.

Computer control of a heavy-media cyclone circuit

To demonstrate the potential of a state-of-the-art computer control system, EPRI contracted with Envirotech Corp. to install and operate automatic controls in a working plant (RP1338-1). The plant selected was the 400-t/h plant owned by Orgas, Ltd., in Keith, West Virginia.

The key equipment in the plant are two 26-in-diam heavy-media cyclones used to separate marketable coal from impurities. After being crushed to 1.5 in or less, the raw coal is mixed with recirculated water and very fine magnetite and pumped to the heavy-media cyclones. The lighter clean coal overflows the cyclones and is then placed on clean-coal drain-and-rinse screens to separate the coarse coal from the finer magnetite, which drops through the screen. The screens also partially dewater the clean coal, which is then further dewatered in a centrifuge before being conveyed to clean-coal storage. The magnetite slurry from the screen is separated into two fractions.

The first, heavy with magnetite and relatively uncontaminated by coal, returns directly to the heavy-media cyclone sump for recirculation. The second, which is dilute in magnetite and more contaminated with coal, has to be pumped to a magnetic separator to remove the magnetic magnetite from the contaminants. The cleaned, concentrated magnetite is recirculated, and the coal is dewatered and stored. The heavier refuse that underflows from the heavy-media cyclones is separated from the magnetite, which is recovered for recirculation; the refuse is dewatered and discarded.

A problem with this type of circuit is that very fine clays liberated from the coal pass through the drain-and-rinse screens with the first cut of magnetite. This clay concentrates in the recirculation loop around the cyclones. Its effect is to increase slurry viscosity, which lowers the efficiency of separation of clean coal from refuse in the heavy-media cyclones.

The automatic controls added to the Orgas plant were used to maintain a constant magnetite density (measured by its magnetic property) and slurry viscosity in the feed to the heavy-media cyclones. This was done by measuring the percentage of magnetics and the slurry density in the feed to the cyclones. An increase in density without a parallel increase in magnetics indicated a clay buildup in the recirculation loop. Some of the thick magnetite slurry would then be automatically diverted from the return to the heavy-media sump to a magnetic separator where the clay could be removed. In practice the control was complicated by such factors as random changes in the coal feed rate, which interfered with the simple relationship between slurry density and percentage of magnetics. These factors were dealt with statistically and the calculations were done on a host computer (a Data General Nova 4X).

The automatic and manual controls were operated on alternate days to ensure fair distribution of the raw coal. Table 1 shows the average results of these runs. A 3.2% improvement in clean coal yield and a reduction from 2.9 to 0.9 in the standard deviation in ash content of the clean coal were achieved under automatic control. On the basis of these results, an annual savings for the plant was estimated to be $250,000–$500,000. These results are specific to this particular plant and the coals it processes. (They are believed to be typical, however.) The economic benefits to be gained from similar automatic control systems at other plants would have to be evaluated on a case-by-case basis.

Table 1
PERFORMANCE OF HEAVY-MEDIA CYCLONES
(Orgas, Ltd., preparation plant)

	Automatic Control	Manual Control
Average ash content (%)		
Feed	32.4	34.6
Clean coal	8.6	9.5
Refuse	72.3	71.3
Clean coal yield (%)	62.6	59.4
Standard deviation of ash		
Feed	5.4	5.2
Clean coal	0.9	2.9
Refuse	7.9	7.2

On-line instrumentation

Although the primary purpose of coal preparation plants is to reduce ash or sulfur concentrations in the clean coal product, it is not possible to control these concentrations directly because there is currently no reliable, rapid, on-line instrument capable of measuring ash or sulfur in a coal slurry. Process control strategies such as that used at the Orgas plant could be much improved by direct control of the ash or sulfur level.

An on-line instrument system capable of providing such measurements is currently being developed for EPRI by Science Applications, Inc. (SAI). The system comprises three separate instruments, each of which provides information necessary to estimate the ash and sulfur concentrations in the solid fraction of a slurry.

- A conductivity gage to measure the volumetric fraction of solids in the slurry
- A dual energy gamma gage to measure the slurry density and to estimate ash concentration, subject to corrections based on iron and sulfur analyses
- A prompt gamma neutron activation analyzer to measure the iron and sulfur concentrations

The instruments are being designed with nonintrusive sensors suitable for use with abrasive slurries and are to be mounted on spool pieces that can easily be fitted into existing pipework. The signals from the instruments are relayed to a minicomputer, which calculates the required data. These data can be displayed for an operator, logged, or used to control the process.

Laboratory-scale versions of these instruments have been tested on a small piping loop through which coal slurries can be circulated. Test results have produced design modifications, which are being incorporated into larger prototype instruments designed for an industrial environment. These instruments are scheduled to be ready for plant testing by mid 1983.

The Coal Cleaning Test Facility will provide a focal point for EPRI's work on control systems for coal preparation plants. It has been designed with this in mind, and it is heavily instrumented and equipped with a digital computer system to be used for process control applications. Instrumentation currently installed includes the following.

- Variable speed sump pumps and thickener underflow pump
- Flow and density sensors on all sump pump discharge lines
- Heavy-media density sensor
- Heavy-media cyclone product weigh feeders
- Pressure transmitters on all cyclones
- Flow control of reagents to the flotation cells
- Disk filter vacuum, pulp level, and speed transmitters
- Automatic samplers on most plant flow streams

The prototype slurry analyzer being developed by SAI will be installed at the test facility in 1983 and provide the basis for an extensive test program on the effectiveness of control-based on-line analysis. The program at the facility will provide two benefits: (1) various control methods can be tried out on a wide range of coals being processed under a wide range of conditions; (2) a large number of coal preparation plant operators can observe and participate in demonstrations of this technology. *Project Manager: Robert Row*

RELIABILITY OF BOILER PRESSURE PARTS

Statistical data on 400-MW and larger coal-fired units collected by the North American Electric Reliability Council (NERC) during the 10-year period 1971–1980 show that boilers and their auxiliary components had an equivalent availability loss of 22.2%. Most of this loss is divided among five major problem areas: maintenance (9.3%), boiler pressure parts (7.3%), boiler heat transfer surfaces (1.6%), pulverizers (1.6%), and fans (1.4%). This report describes current and planned research to determine why boiler pressure parts fail and to develop improved technology for failure prevention, control, and maintenance.

Boiler pressure part failures fall into two categories: (1) tubes, which fail relatively frequently, but which take a relatively short time to repair, and (2) drums and headers, which fail infrequently but sometimes catastrophically and take a long time to repair or replace. The 7.3% boiler pressure part loss is distributed among waterwall tubes (~4%), superheater and reheater tubes (~2.2%), and drums, headers, and pipes (~1.1%).

Waterwall tube failures

Two common types of waterwall tube failures are those resulting from waterside and fireside corrosion. Investigations of waterside corrosion failures have clearly demonstrated that the predominant root cause is deposition of copper and iron corrosion products from the preboiler feedwater cycle (the feedwater heaters, the extraction steam piping, and the condenser) in conjunction with upsets in feedwater chemistry. Waterside corrosion rarely occurs unless preboiler corrosion products (PCPs) have been deposited.

EPRI research endeavors to develop improved technology for reducing the generation, transportation, and deposition of PCPs. Additional research may also develop advanced chemical cleaning techniques and materials/coatings that are more resistant to waterside corrosion. Three studies are currently under way to reduce tube failures caused by waterside corrosion.

One effort is the development of a water technology handbook to provide utilities with current state-of-the-art power plant water technology, such as water treatment practices, feedwater chemistry control, polishing demineralization, filtration, and deaeration (RP1958). A second project will develop a chemical cleaning manual on the how, when, and what to use to chemically clean power plant equipment, primarily boiler tubes (RP1608). The third project is investigating the control of PCP deposition on waterwall tubes by the use of polymer dispersants, which have been found to be very effective in low-pressure boilers. This study is evaluating these additives' thermal stability and the effects of decomposition products on all system components in high-pressure and high-temperature boilers (RP2158). A fourth project, planned for 1983, will assess the effects of waterside corrosion on waterwall tube reliability and the limitations of state-of-the-art prevention and control technology in coping with such operating problems as cycling operation and extended service of old plants.

The most probable root cause of fireside corrosion is localized sulfidation resulting from slag deposits in a substoichiometric combustion environment. Damaging corrosion (wall wastage) does not usually occur unless both conditions are present. Therefore, the research on this problem is primarily to develop sulfidation-resistant tube materials/coatings and better control systems for combustion monitoring. One project, scheduled for 1983, will assess current technology for fireside corrosion prevention and control in today's plant operating environment to determine its limitations and to plan future research.

Superheater and reheater tube failures

Superheater and reheater tubes fail less frequently than waterwall tubes but take longer to repair because of their location. Waterwall tubes can usually be repaired in 48 hours; superheater and reheater tube repairs require 100 hours or more. Two common types of tube failure that occur in these boiler regions are the failure of dissimilar metal welds (DMWs)—welds that join two dissimilar tube materials together—and failures resulting from fireside corrosion. The root cause of DMW failures is unknown at present. Most investigators consider ash deposits and the formation of alkali iron trisulfates to be the root cause of fireside corrosion failures.

A major research effort (RP1874) to address the DMW problem has defined four major objectives: to identify DMW-failure root causes; to develop a methodology for estimating the remaining life of these welds; to develop an accelerated test to evaluate and rank welds in less than 2000 hours; and to develop guidelines for improved DMWs. Scheduled to be completed by 1984, this project has made substantial progress toward achieving all four objectives. A seminar will be held in the fall of this year to disseminate project results, and demonstrations of the remaining-life methodology at four or five utility units are planned for 1984.

Another project on fireside corrosion of superheater and reheater tubes is planned for 1983. Small tube sections coated with magnesium zirconate will be installed in a few utility boilers that have suffered severe fireside corrosion. In laboratory tests simulating field corrosion conditions, this coating (developed under RP644-1) has demonstrated a marked resistance to fireside corrosion caused by alkali iron trisulfates.

Tube failures—general

Utility boiler tubes fail for many reasons, and the need to limit outage time often dictates that a unit be restored to service as soon as possible without determining the actual cause of failure, which can result in additional failures a short time later. Tube failures will continue until root causes are determined and proper corrective or preventative action is taken. To provide utilities with this essential information, an operations manual is being developed on common types of boiler tube failures (RP1890-1). This manual will contain physical and metallurgical descriptions, locations of typical failures, most-probable root causes, state-of-the-art inspection techniques, tests for verification of cause, and current recommended failure prevention and control and tube repair practices. This manual, developed primarily for use by plant operating and maintenance personnel, will be published by the end of this year.

Drums, headers, and piping

Thick-wall pressure parts do not fail very often. Using current life-assessment techniques, utilities usually replace them when further operation is considered unsafe—before failure actually occurs. Because failure or replacement of these components requires long outage times, the decision to replace these parts is a very costly one for utilities to make. Many experts consider present life-estimation methodologies inadequate for providing many of the facts necessary to make this decision. The methodologies must answer questions raised by today's utility operating and economic environment. How can the lives of older units be extended? What is the effect of cycling? How much life really remains in a particular unit? Can a reliable life estimate be predicted by using nondestructive rather than destructive tests?

Research to provide answers to most of these questions has just begun. Project goals are to develop life-prediction methodologies that are more accurate than present methods, that are essentially nondestructive in their application, and that can evaluate materials used in critical boiler thick- and thin-wall pressure parts (RP2253). The project will develop and validate a combination of metallographic evaluations and miniature-specimen stress rupture tests for utility use in estimating the remaining creep life of boiler headers and tubes.

Recognizing the serious financial impact that boiler pressure part failures have on utility resources, EPRI is working toward providing technology that will reduce failures of these components. Other related research currently being conducted within the Availability and Performance Program of the Coal Combustion Systems Divison are studies of condenser deaeration and leakage, boiler performance monitoring and diagnostics, nondestructive techniques for boiler inspections, root cause analysis of unusual types of pressure part failures, systems for on-line stress analysis of critical boiler components, and computer codes for analyzing boiler operations under dynamic and cycling conditions. *Project Manager: John Dimmer*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

Enhancement of the EMTP

The transient behavior of a power system is often the critical factor in determining its design and the equipment required. For many years, studies of high-speed electromagnetic transients (e.g., insulation coordination) were performed with small analog computer models. In the last decade a digital computer electromagnetic transients analysis program (EMTP) was developed and distributed by the Bonneville Power Administration (BPA) to perform these studies conveniently and inexpensively.

EMTP grew rapidly in a piecemeal fashion to meet the needs of individual studies. The result is a computer program that is unable to study many phenomena of interest, is inadequately documented and tested, and is very difficult to use. These problems have greatly reduced the use of the program by electric utilities.

A properly developed EMTP would allow a utility to save up to 90% of the cost of design and disturbance studies now contracted to consultants because of the lack of inhouse capability. The greater flexibility of doing studies in-house helps ensure that important scenarios are not overlooked. Controlled program distribution promotes the industrywide use of state-of-the-art analysis and design techniques.

A project has recently begun (RP2149) to provide a summary and analysis of what could be done to EMTP to make it more useful to EPRI member utilities. Six workshops, surveys, and consultations with current and potential users of EMTP will produce a list of desired enhancements. The type, amount, and implementation costs of these enhancements will be analyzed. Work desired will be ranked in order of priority to utility users. If sufficient justification for further EPRI-sponsored work is evident, the results of this project will be used to choose the content of any future EPRI effort to implement changes to EMTP. Westinghouse is the contractor. *Project Manager: James Mitsche*

DISTRIBUTION

Decay in pine poles

A recently completed project with the State University of New York at Syracuse (RP1471) addressed the effective arrest and control of fungi growth in southern yellow pine poles by the application of the fumigants Vapam and chloropicrin. (The project was a follow-on to RP212, in which Oregon State University demonstrated arrest and more than 10 years' control of fungi growth in Douglas fir poles by using these fumigants; *EPRI Journal*, July/August 1982, p. 43, and November 1982, pp. 18–20). Using southern yellow pine poles of known age and initial treatment, the total fungal population in each of 51 poles was determined. With this data as a base, 33 poles were treated with Vapam and 18 with chloropicrin. Pole segment samples from utilities in other areas of the country were also examined for fungal population to verify that the test poles contained a representative population of fungi for all poles.

The detailed and intensive cultural and microscopic study of the test poles identified hundreds of individual fungi and bacteria present in poles of varying ages. The decay capacity of each was determined; the tolerances and sensitivities of the major fungi to creosote, penta, Vapam, chloropicrin, and Vorlex were also determined. The analysis of these data shows a pattern of fungi invasion and provides evidence of both outside-in and inside-out development of decay, the latter being attributable to pockets of decay not arrested by the initial pole treatment.

Examination of the poles one and two years after treatment with Vapam and chloropicrin showed that no active fungi were present. The project is being extended to observe fungal reinvasion patterns and determine the period of control beyond two years.

In another task, the relative effectiveness of decay detection in a series of test poles was determined for electrical resistance (Shigometer), X-ray radiographs, impact energy absorption (Pilodyne), cultural methods, and torque reduction during boring. Though no one of these methods is totally reliable, certain combinations can improve one's confidence level in detecting decay.

The service life of southern yellow pine poles can be extended by arresting and controlling decay with the fumigants. It is anticipated that as in Douglas fir, the period of control may be well in excess of two years. Pole replacement costs deferred for this period of time represent substantial savings to utilities. *Project Manager: Robert Tackaberry*

Distribution automation

The benefits and desirable features of a truly comprehensive control for distribution systems were fully described in the *EPRI Journal*, January/February 1982, p. 44 (RP1472). The hardware and associated software being developed in this project are the integrated distribution control and protection system. An engineering prototype of the system is under construction and will be installed at the Handley Substation of Texas Electric Service Co. by late 1983, and field trials will be carried out during 1984.

The integrated system comprises four subsystems: a substation integration module (SIM), a data acquisition system (DAS), a digital protection module (DPM), and a feeder remote unit (FRU). SIM coordinates the function of the last three subsystems by collecting their data to form and maintain the real-time data base required for substation and feeder control. SIM also maintains a communication interface with a higher-level center (attended location) in the overall automated distribution system structure, such as a DDC, SCADA master, and/or load management system. A man-machine interface is available for display, logging, control, settings, and the changing of other system parameters (Figure 1).

DAS modules include interfaces with the substation equipment for acquiring analog and contact status, and they provide control interfaces for circuit breakers, switches, and transformer load tap changers. Typically, a DAS is provided for each controlled or monitored breaker or switch (i.e., transformer, bus tie, or feeder). Acquired data are processed locally within DAS and are reported to SIM for control and monitoring purposes when DAS is polled by SIM. Control commands are received from SIM and executed by DAS (e.g., open/close breaker, raise/lower load tap changer).

DAS–DPM modules are used for data acquisition and control plus protection. A DAS–DPM is provided on each breaker when digital protection is used. Local man-machine interface is provided to permit the user to enter and change protection settings and for display. Alternatively, the protection settings and display are also available at the SIM man-machine interface.

FRUs are data acquisition and control modules at remote locations on the distribution feeders. Bidirectional communication between SIM and FRUs is by a distribution communication system—a distribution line carrier, radio, or telephone. FRUs acquire analog data and contact status, sense feeder faults, and report the data when polled by SIM. They receive commands from SIM for the control of feeder sectionalizing switches, feeder-switched capacitor banks, feeder voltage regulators, and feeder reclosers. FRUs are typically pole-mounted.

Handley Substation is located at Fort Worth and is served by the 138-kV buses of Handley Generating Station, which is adjacent to the substation. Three 22.4-MVA, 138-kV/12 5-kV transformers with load tap changers supply three stations of 15-kV metal-clad switchgear. Each switchgear station serves two feeders. Bus-tie circuit breakers are situated between the switchgear stations. Motor-operated air switches are installed in the 138-kV leads of each substation transformer. Transformer secondary circuit breakers are provided in the 12.5-kV leads of two of the transformers, and a motor-operated air

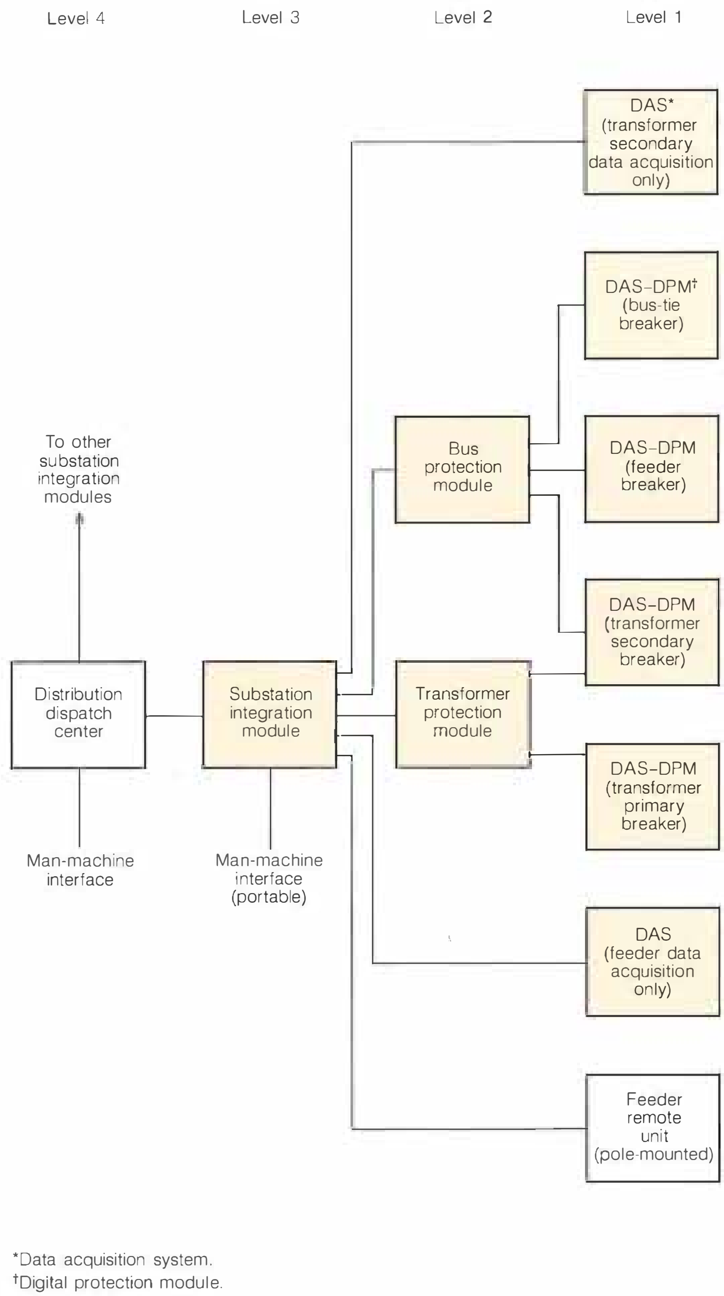


Figure 1 The substation integration module coordinates the functions of the data acquisition and control system, the digital protection module, and feeder remote units by collecting data from them and forming the real-time data base required for substation and feeder control. The digital protection module operates in coordination with the data acquisition system and is also a stand-alone device. (Shaded units are located within the substation.)

switch is installed as a transformer secondary switch in the 12.5-kV leads of the third transformer.

SIM is equipped with a local man-machine interface (color CRT and printer) and communicates with Tesco's SCADA master on leased telephone lines.

DASs and DAS–DPMs are designated for three totalizing breakers and switches, two bus-tie breakers, and six feeder breakers and are installed in 15-kV metal-clad switchgear stations.

FRUs are pole-mounted along two Handley feeders and situated at eight capacitor bank locations and seven sectionalizing switches.

The Intel microprocessor family has been selected as the standard, with the 16-bit Intel 8086 as the processor used in most applications. The software for these modules is stored on nonvolatile EPROMs (electronically programmable read only memory) for execution by the microprocessor. The software contains routines for sampling data, scheduling the flow of processing, control, and on-line system self-test.

SIM collects and integrates data and control information from the DAS and FRUs that are distributed throughout the distribution substation and feeders. SIM processes the data and provides output in the form of alarms, reports, or required operator actions.

The distributed communication network is based on the need for periodic sampling of analog parameters, contacts, switch status, and event-driven control outputs. The sampled data are integrated into a common data base for control function access and for monitoring and reporting functions. The distributed system also provides for distributed control of breakers, reclosers, and transformer load tap changers where the control action originates from a manual operation at SIM or at a higher level or as a result of a control algorithm decision to isolate faults and/or to reconfigure the distribution network. The communication subsystem is a point-to-point polled link between SIM and each DAS and a distribution communication system for FRUs with SIM software polling.

The control function software developed for the EPRI project consists of integrated volt-VAR control, feeder deployment switching and automatic sectionalizing, and automatic bus sectionalizing. Additional functions, such as transformer load balancing or load management, may be considered for implementation at a later time.

The functions to be developed under the EPRI project required large software modules on the order of 2000 program design language statements each. They are basically conditional or logic processes as opposed to computationally intensive algorithms, such as transmission directional comparison schemes, and require relatively slow response times on the order of many seconds. The control functions do interrelate and therefore have to share a common database of dynamic substation parameters, and their control actions have to be coordinated by a common control executive.

The monitoring functions continuously scan incoming data from remote DASs and FRUs, and alert operations to alarm conditions, uncommanded status changes, or other anomalies in the power system.

The hardware required to support the SIM processing requirement includes five Intel 8086 microprocessors configured in a distributed architecture linked by a multibus and common global memory.

One microprocessor is required to support the control and data monitoring functions. Data base support functions will be allocated to this processor to maintain the global database required for communication and user interface.

Two microprocessors are required to support the communication interface of up to 40 DASs and 200 FRUs. These processors provide multiple channel multiplexing, error detection and retransmission, and protocol processing.

The microprocessor for man-machine interface is dedicated to supporting color graphics and the logging printer interface with SIM. This processor provides the color graphics data base, output generator, and command processing software.

A separate microprocessor has been allocated to the SCADA interface for the EPRI project. After further analysis of the loading requirements of this function, the software may be allocated to one of the other processors.

DAS provides interfaces to the power system for acquiring analog data and contact closure status and provides control interfaces for breakers, load tap changers, and other control mechanisms. The acquired data are either reported up to a SIM for substation control function processing, used locally in the DAS or the DAS–DPM for protection processing, or transmitted to a Level 2 module, such as bus differential protection.

DAS will be located near the appropriate power system components. The electronics will therefore be required to survive severe temperatures (-20 to $+55\,^{\circ}$C) and electromagnetic interference conditions. DAS will be powered by substation batteries, must be isolated from interference caused by radiated or conducted noise signals, must condition the primary transformer signals for processing, and have computation capability for data management, protection, and control.

The basic DAS architecture provides for simultaneous acquisition of data and processing through a shared memory. Functions can be added to the basic architecture to meet optional requirements. When all the currently defined functions are added, DAS has the capability to sense zero crossing for underfrequency detection, interface to transformer load tap changers, and acquire slow analog data for such devices as top-oil temperature thermocouples. When a protection microprocessor is included, the module becomes a DAS–DPM.

FRUs are designed to be installed at remote locations on utility power distribution feeder poles and contain a subset of the DAS capability. FRUs monitor and control sectionalizing, tie, and capacitor bank switches and power system overcurrent fault detectors and will also acquire power system voltages and currents.

FRUs will receive discrete and analog signals as inputs, which are converted to digital format for transmission to SIM. Similarly, FRUs will receive data in digital format from SIM and convert them to power system control outputs (contact outputs).

The primary design objectives for FRUs are simplicity of operation and reliability. A FRU will consist of three or four digital electronic boards housed in a National Electrical Manufacturers Association enclosure of reasonable size that can be mounted on a utility pole. The FRUs will operate continuously from an ac power source without maintenance in the severe remote feeder environment.

Success in the development of the hardware and software thus far gives us confidence that this system will meet or exceed its design objectives; many of the subsystems should be commercially available for application by mid 1984. *Project Manager: Thomas Kendrew*

OVERHEAD TRANSMISSION

Polysil* transmission line structure

EPRI, Florida Power & Light Co., and the contractor, Hughes Supply, Inc., are jointly funding the development of a single-pole 138-kV structure with Polysil (RP2015). Polysil is a good insulating and structural material, and a transmission structure is an

*Polysil is an EPRI trademark.

ideal use of these features. A vertical configuration was selected, both to minimize right-of-way requirements and to create a slim, neat appearance.

To visualize this design, think of four 138-kV post insulators stacked in a column with an overhead ground wire on top and a phase conductor attached at the top of the three lower insulators (Figure 2). Then, add a single shaft to support the assembly. Although this is not practical with porcelain insulators, the features of Polysil permit the fabrication of a mechanically strong and cost-competitive structure.

Now that initial testing is complete and the design concept has been selected, detailed engineering is under way. It is planned to fabricate the top section as a unit; the lower portion of the pole will be made in various lengths and joined to the top section in the field.

Prototype structures will be tested mechanically and electrically both in the laboratory and in the field. When this structure is available commercially, transmission line engineers will be able to build lines within a narrow right-of-way, using an uncluttered profile that should be well received by the public. *Project Manager: John Dunlap*

TRANSMISSION SUBSTATIONS

Fluid-cooled power transformers

Research on two competing technologies of two-phase cooling for transformers is nearing completion (RP1499). The cost target for both technologies is to be able to compete with, or be lower than, the total cost of owning a conventional oil-filled transformer.

The first, by Westinghouse Electric Corp., uses fluid tetrachloroethylene (C_2Cl_4) mixed with transformer oil (75-25%). The mixture is used to increase the dielectric strength and lower the pour point. The transformer is so designed that the fluid does not boil but simply takes advantage of its better heat transfer capabilities. Earlier versions of this transformer design did employ change-of-state from liquid to vapor; however, this design uses two-phase cooling only at hot spot locations during severe overloads, which is why it is referred to as fluid-cooled (either liquid or vapor). A model single-phase unit has been built and tested. The conclusions reached after examining the test results indicate that the temperature of the windings and liquid was substantially lower than if the unit had been tested in oil alone. This allows the designer to increase the space factor of the winding by decreasing space between sections of the winding and other cooling ducts, which not only decreases the cost but also reduces the losses.

Cost analysis indicates that the objectives of the project have been met. A 65-MVA, 138–13.8-kV prototype unit will be built for installation on the system of Consolidated Edison Co. of New York, Inc., for a two-year field evaluation, during which installation, maintenance, and performance will be monitored.

The second technology, investigated by General Electric Co., uses liquid trichlortrifluoroethane ($C_2Cl_3F_3$; R113). This liquid boils at 47°C and consequently does so during normal operation of the transformer, thereby taking advantage of the latent heat of vaporization to very effectively cool the transformer. Although this allows the space factor to be greatly reduced, the nucleate boiling of the liquid on the surface of the conductor results in a considerable reduction in the dielectric strength of the transformer. Also, the cost of the liquid is quite high ($13/gal). Consequently, the cost of the transformer so far has not met the objectives of the project. At the present time

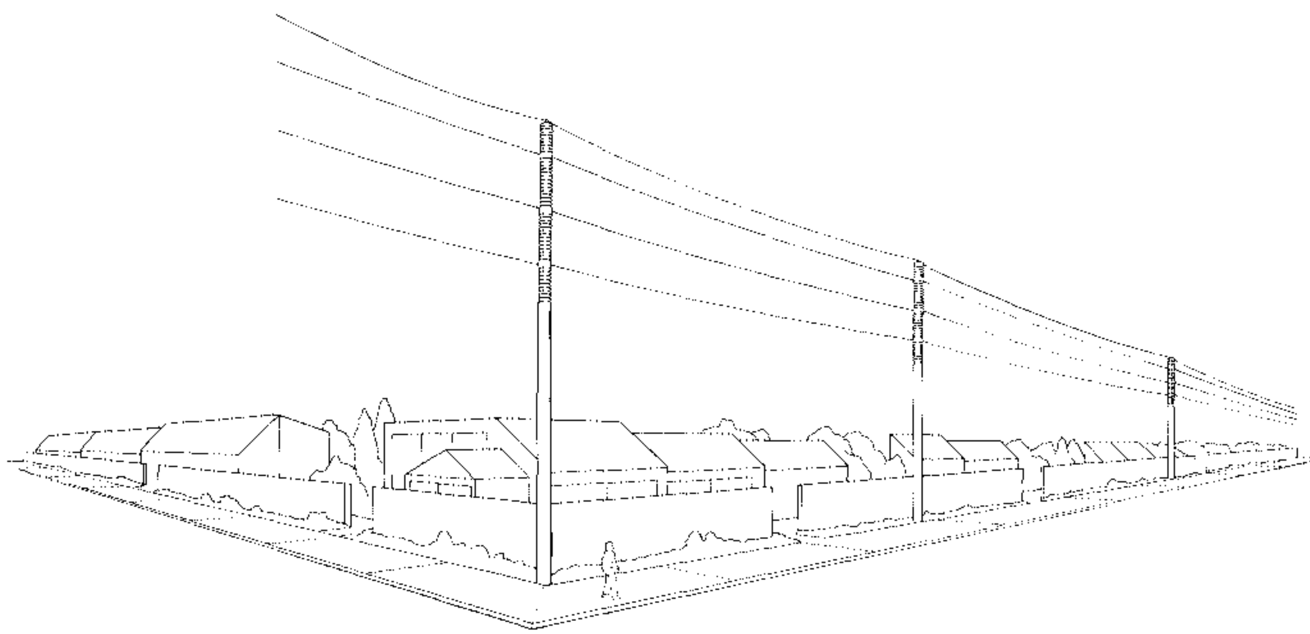


Figure 2 Illustration of the Polysil structure, emphasizing both its structural and its insulating features. Note that the conductors can be attached directly to the pole, creating a compact structure that has a pleasing appearance.

it is anticipated that only the single-phase model will be built so final test results can be examined. *Project Manager: Edward Norton*

SF_6 compact capacitors for ac and dc transmission substations

Capacitor banks are an important part of bulk power ac substations and dc converter stations. But they present two problems: they occupy a large area (particularly in HVDC and large EHV substations), and they attract rodents, snakes, and birds because of their warmth and open-lattice structure.

A 400-MVAR shunt capacitor installation for a 345-kV transmission line may occupy a space exceeding 4000 m^3 (140,000 ft^3). The capacitors themselves take up as little as 2% of this space, in spite of the fact that individual capacitor units are rated up to 200 kVAR. The interface spacing and insulation-to-ground requirements account for 98% of the space. The large space required for capacitor banks is even more apparent in modern converter stations, where 30% or more of the converter terminal yard is required for the ac harmonic filter and shunt capacitor installation.

EPRI is jointly sponsoring a project with Consolidated Edison to develop a compact capacitor bank suitable for ac as well as HVDC stations (RP996). The objective for the design is to reduce the volume of a capacitor bank to about one-tenth of the air-insulated alternative at an evaluated cost equal to or less than the cost of a typical conventional air-insulated alternative. The basic design concept is to place an assembly of individual capacitor units in a pressurized sealed tank. Such a design must meet many stringent requirements.

The tank must withstand the internal pressure, selected to be less than 100 kPa (15 psig) over pressure. But the tank may also have to withstand vacuum, which is often used to remove moisture from the interior of electrical apparatus. In addition, the internal support structure for the capacitor units must be strong enough to withstand shipping stresses and (in some areas) seismic stresses. The mechanical assembly must also be built to allow for maintenance of the capacitor because failed capacitor units will have to be replaced, although (it is hoped) at infrequent intervals. The target for capacitor maintenance is not more than once every five years. To achieve this, internally fused capacitors were selected.

Capacitor losses, while very small, have to be considered in the design. For this compact design it is important to use as few capacitors as possible. The fact that the capacitors are placed inside a pressurized tank allows a capacitor uprating to about 120% of normal. In addition, if the capacitor dielectric temperature can be maintained between 10°C and 55°C, the reliability is expected to be greatly improved. For these reasons, the tank was given an external layer of polyurethane foam and a forced-gas heating/cooling system was added. Heating of the capacitors would be used for startup conditions (energization would take place first, after heating the capacitors to 10°C). Cooling would be needed after energization of the capacitor bank.

The capacitor assembly must also be able to handle the dielectric stresses. It was recognized from the outset that it would be difficult to test the dielectric integrity of the design because there is no test equipment available that can generate the test energy required. It was first determined that the capacitors acted like big filters for fast (lightning impulse) transients. For this reason, the dielectric test requirements for fast front surges (1–10 μs) could be reduced to equal the peak of the switching surge (200–2000 μs) test level. Low-capacitance capacitors were manufactured and installed to make dielectric testing possible.

The subsequent testing revealed serious deficiencies in the first support structure, and a complete redesign was undertaken. The second attempt, however, was successful, which proved that the refined design methods were correct. The mechanical integrity was tested through a shipping test. Heat runs also proved the thermal design concept.

The economic viability of the design was rechecked at the conclusion of the factory test phase. The results of this were disappointing. They showed that the design was not competitive with the air-insulated alternative. Consequently, the design concept was reevaluated and changed, primarily in the area of internal capacitor support structure. The analysis indicated that substantial cost reductions were attainable without compromising any of the requirements. In fact, it was found that several other improvements were also achievable—for example, a more maintainable structure.

The new design was proposed by and contracted to Westinghouse and is now under way (RP996-2). The prototype produced by Brown Boveri Corp., will be used to confirm the assumptions made for capacitor reliability through high-voltage, long-term testing at the Underground Cable Test Facility, Waltz Mill, Pennsylvania. *Project Manager: Stig Nilsson*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

RESIDENTIAL CUSTOMER RESPONSE TO TIME-OF-USE RATES

Predictions of customer load response to alternative time-of-use (TOU) electricity rates are an important input to the design of cost-effective TOU rate programs. Several methods can be used to make these predictions, including experimentation, historical analysis, simulation, and techniques for transferring results from experiments conducted in other regions. During 1975–1981 DOE and a number of electric utilities conducted 14 experiments involving TOU rates for residential customers. Although studies have analyzed individual experiments, the transferability of the DOE results as a whole to the rest of the country has not been addressed. If information on customer response patterns can be transferred across geographic regions, many utilities may be able to avoid conducting expensive, time-consuming experiments. Under RP1956 transferability issues are being investigated, and data from the DOE experiments are being used in the development of an econometric transferability model for predicting residential load response to TOU rates.

Several factors determine the type of load response that results when a specific TOU rate is implemented. One of the critical factors is the composition of the rate structure itself—that is, the number and timing of pricing periods and the rates charged during each period. Other factors include the general rate level, the region's climatological profile, and the general makeup of the customer population, as characterized by its sociodemographic, economic, and appliance ownership distributions. If the relationship between customer response and these conditioning factors can be properly measured—say, by analyzing data from regions where controlled experiments with TOU pricing have been conducted—utilities in other regions may be able to predict customer load response by modifying results from the experimenting regions. The transfer of load shape information, then, may represent a cost-effective alternative to primary experimentation.

In RP1956 nine of the DOE projects on residential TOU rates have been examined. Table 1 summarizes their important design features. Most projects lasted for one or more years and involved several TOU rates. Because the projects together covered a wide variety of rate levels and climatic conditions, the results developed from this composite experimental data base should be of value to utilities throughout the country.

For the purpose of data analysis, a measure of customer response, *B*, that relates changes in load shape to changes in the TOU rate structure has been defined. In the simplest case of two pricing periods, *B* is a constant term that relates the ratio of peak to off-peak energy consumption to the ratio of peak to off-peak electricity prices. In more complex formulations developed in the project, *B* is made a function of customer characteristics, such as appliance portfolio, sociodemographic profile, and economic status. The measure is related to the standard price elasticities of consumer demand analysis. Its numerical value increases as the substitution of off-peak energy for peak energy increases.

Table 2 reports the estimates of *B* that

Table 1
DESIGN FEATURES OF SELECTED DOE EXPERIMENTS ON RESIDENTIAL TOU RATES

Experiment	Test Period	No. of Participating Customers	No. of Alternative TOU Rates
Arizona (Arizona Public Service Co.)	May–October 1976	140	28
Arkansas (Arkansas Power & Light Co.)	February 1976–January 1977	1404	1
California (Southern California Edison Co.)	March 1979–February 1981	600	8
Connecticut (Connecticut Light and Power Co.)	October 1975–October 1976	400	1
Los Angeles (Los Angeles Department of Water & Power)	June 1976–June 1979	1268	34
North Carolina (Blue Ridge Electric Membership Corp.)	October 1977–October 1978	200	1
North Carolina (Carolina Power & Light Co.)	December 1977–May 1979	600	13
Oklahoma (Edmund Municipal Electric Co.)	September 1977–August 1978	600	6
Wisconsin (Wisconsin Public Service Co.)	May 1977–May 1980	644	10

resulted when the substitution of off-peak for peak energy on an average summer weekday was assessed for five of the DOE experiments. The average-household results are remarkably similar across the five projects. The results are more varied for the other two categories: households with no major electrical appliances (air conditioner, water heater, clothes dryer, range, and dishwasher) and households with all the major electrical appliances. In each experiment, however, appliance ownership significantly affects customer response, resulting in more substitution of off-peak for peak energy.

The implications of the differences in customer response estimates by type of household are traced out in Figure 1. As the ratio of peak to off-peak price increases from 1:1 (i.e., a flat rate) to 8:1, the portion of total consumption represented by peak period consumption on an average weekday can be expected to decline by nine percentage points for a household with all the major electrical appliances. For a household with no major electrical appliances, the portion will decline by only half a percentage point. For the average household, the portion will decline by seven percentage points.

Customer response was compared across peak days and average weekdays for the average household. Little difference was discernible in the response patterns. Thus the skepticism voiced by some analysts about the effectiveness of TOU rates on days of the system peak is not borne out by the experimental data.

The experiments show, on average, a 10% reduction in overall electricity usage. It should be noted that this reduction is not related to an increase in the overall price of electricity, because the experiments were designed to keep the average price the same if consumption patterns remained unchanged. The observed conservation has to be attributed to a change in consumer preferences that resulted when the households were placed on TOU rates.

The transferability project is currently addressing model enhancements. For example, modifications are being implemented to enable the model to analyze load shape changes not only at the level of two or three pricing periods but also at a much finer level of resolution involving essentially hour-by-hour changes during the daytime. Other enhancement activities under way include an assessment of the effect of climate on customer response estimates and an investigation of aggregate price elasticities.

With these enhancements, the transferability model should permit virtually any utility to predict load shape modifications arising from alternative TOU rates. As input to

Table 2
ESTIMATES OF LOAD RESPONSE MEASURE (*B*)
(average summer weekday)

Experiment	Average Household	Household With No Major Appliances	Household With All Major Appliances
California	0.14 0.16	−0.01 0.06	0.21 0.22
Connecticut	0.12	0.05	0.19
Los Angeles	0.14	0.09	0.33
North Carolina (Carolina Power & Light Co.)	0.16	−0.18	0.11
Wisconsin	0.13 0.13 0.14	0.10 0.10 −0.03	0.13 0.13 0.29
Average (excluding Los Angeles)	0.14	0.01	0.18

Note: The California results are for two tests with the same peak period duration but different peak period timing. The Wisconsin results are for tests with different peak period durations: 6, 9, and 12 hours, respectively. The Los Angeles experiment is not currently included in the average because of the large size of its data set. It will be included in the final version of the transferability model, however.

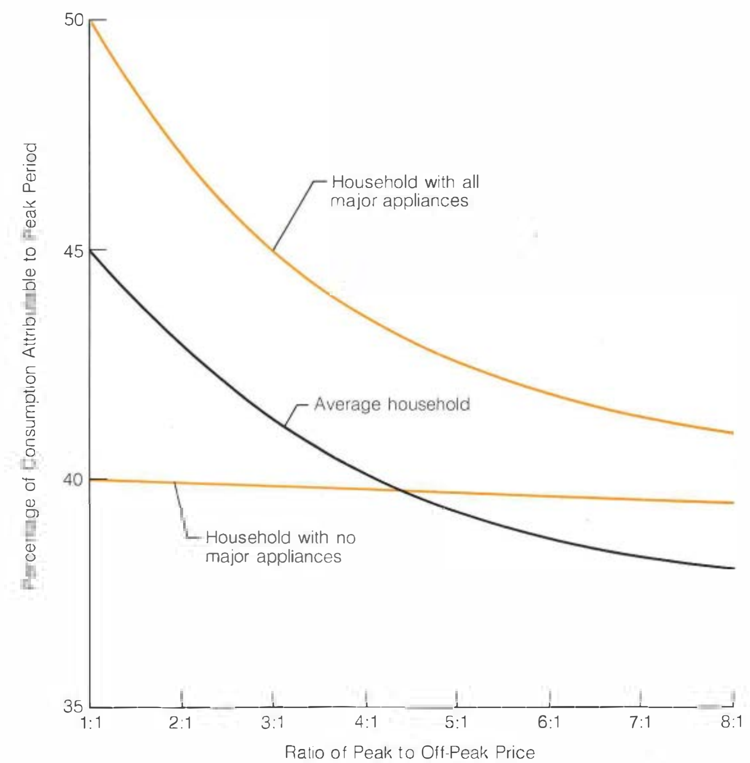


Figure 1 Effect of TOU rates on peak period electricity consumption (as a percentage of total consumption) for an average summer weekday. Appliance ownership clearly increases the degree to which households substitute off-peak for peak energy under TOU pricing.

the model, a utility user would need to supply data on baseline load shape; customer sociodemographic, economic, and appliance ownership characteristics; climate; and rate structure and level. To demonstrate the modeling procedure, two case study applications are planned. *Project Manager: Ahmad Faruqui*

INDOOR AIR POLLUTION

Indoor air pollution research at EPRI, which began with a comparison of indoor and outdoor air quality, is advancing into several focused studies that have application to programs in both energy conservation and human health. The results of the early work (RP1309) and the design of the new projects are outlined here. Detailed results of RP1309 are presented in EA-1733 and EA-1025.

Two factors have provided the impetus for indoor air pollution research at EPRI. One is that energy conservation efforts have led to the tightening of homes against the infiltration of outdoor air; the other is that most people spend more than 75% of their time in an indoor environment. The first factor means that indoor levels of pollutants with indoor sources will tend to increase, possibly affecting the health of occupants, while pollutants primarily of outdoor origin will tend to be less concentrated indoors. The second factor implies that air pollution epidemiology studies, which in the past have relied exclusively on outdoor monitoring to establish human exposures, must also account for exposures indoors—exposures that may be quite different from what outdoor monitoring indicates.

EPRI research on indoor air pollution began with a study that compared indoor and outdoor concentrations of selected pollutants at ten residences and two office buildings. The results showed that SO_2 and O_3 concentrations were consistently higher outdoors than indoors, whereas CO_2 and nonmethane hydrocarbon levels were consistently higher indoors. Concentrations of CO and NO_x were generally found to be greater indoors than outdoors for residences with gas facilities, whereas the levels of these pollutants in all-electric homes were similar to outdoor levels. Concentrations of total suspended particulates were consistently higher indoors at all residences, but the difference was greater at residences where the occupants smoked.

These relative indoor and outdoor pollutant concentrations point up the importance of indoor sources on concentrations indoors. For example, Figure 2a depicts the concen-

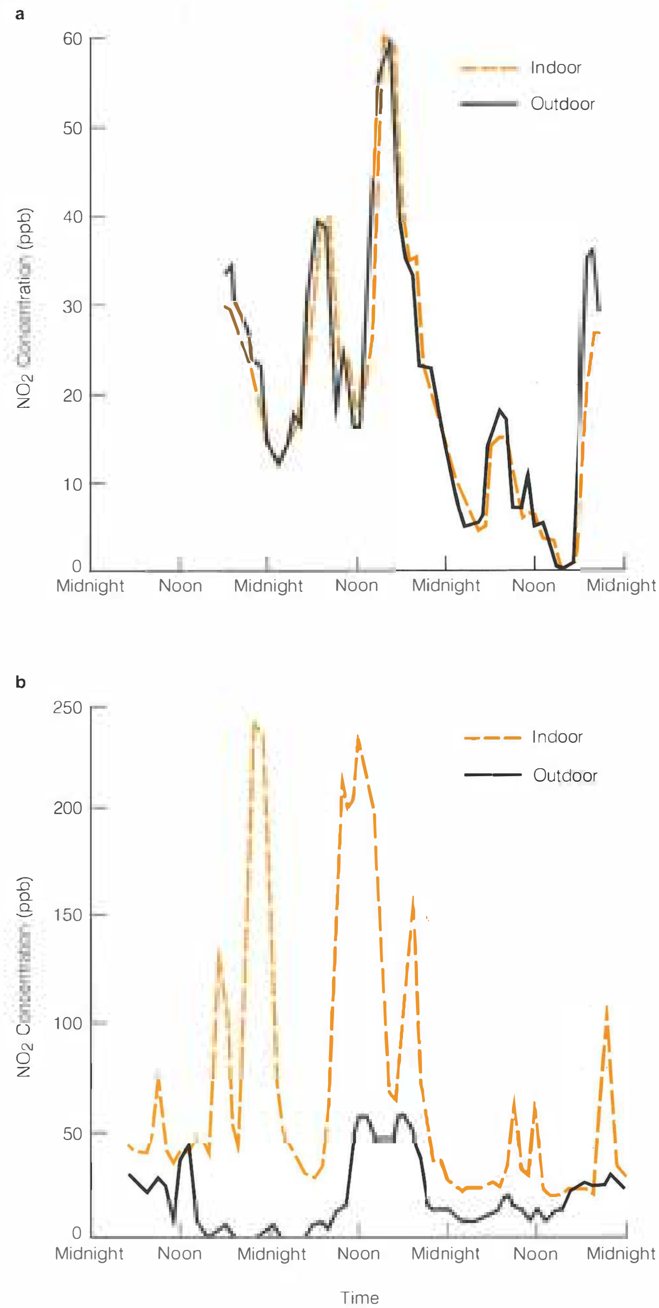


Figure 2 Hourly indoor and outdoor NO_2 concentrations for (**a**) an all-electric residence, and (**b**) a residence with gas appliances. The elevated indoor levels at the latter indicate the importance of indoor sources. (Note the difference in the *y*-axis scales.)

tration history of NO_2 inside and outside an all-electric residence. The concentrations are essentially the same. In Figure 2b, which shows NO_2 concentrations inside and outside a residence with gas appliances, the effect of indoor sources is clearly evident.

Just how important indoor sources are and how their impact is influenced by the exchange of indoor and outdoor air are two questions being addressed in a recently initiated project on energy use, infiltration, and indoor air quality in tight, well-insulated residences (RP2034). The project is being managed jointly by the Energy Analysis and Environment Division, which is responsible for the indoor air quality aspects, and the Energy Management and Utilization Division, which is responsible for the energy use aspects. The common ground is infiltration, since it affects both indoor air quality and energy use.

Geomet, Inc., is conducting the study at two adjacent newly constructed houses. The houses are identical and have an indoor-outdoor air exchange rate of about 0.5 turnover per hour. Indoor air quality, energy use, and air exchange rates are being monitored initially to establish baseline values. One of the houses will then be tightened to lower the hourly air exchange rate to about 0.25, and an air-to-air heat exchanger will be installed to allow the rate to be varied. Further monitoring of both houses will enable researchers to assess quantitatively how air quality and energy use are related to air exchange rates. The effectiveness of the air-to-air heat exchanger in recapturing otherwise lost heat will also be quantified.

The study will focus on air pollutants for which indoor sources predominate, including CO, NO_2, CO_2, radon, formaldehyde, and inhalable particulate matter (i.e., having an aerodynamic diameter of less than 10 μm). Each pollutant will be monitored inside and outside the houses. Occupancy will be simulated by the study team in a controlled manner so that the effects of activities influencing source emissions (cooking, cleaning, bathing) and air exchange (the opening and closing of doors and windows, exhaust fan use) can be closely monitored. Air exchange rates will be determined by monitoring the decline in concentration of a tracer gas periodically released into the houses. A strict regimen of heating and cooling equipment use and air-to-air heat exchanger use will be followed for one year. The data collected will thus be representative of a range of ambient conditions and demands on the heating, ventilating, and air conditioning systems.

The initial EPRI project included the development and preliminary testing of a simple mass balance algorithm for predicting indoor pollutant concentration as a function of outdoor pollutant concentration, indoor source rate, air exchange rate, residence volume, and a decay factor (RP1309). The current project will build on this work (RP2034). The mass balance air quality model will be tested against the collected data and modified as indicated. In addition, a similar testing and improvement effort will be conducted for a residential energy use model. A key aspect of both efforts will be the incorporation of a dynamic infiltration prescription that accounts for the dependence of air exchange on building physical factors and on environmental factors. The goal is to produce a model of energy use and indoor air quality (as linked through infiltration) that can predict the effects of tightening on each and can also be used to assess the trade-offs that may be required between the two.

RP1309 also developed the concept of estimating total exposure, outdoor and indoor, through a three-dimensional representation of concentration, time, and location. An index of total exposure must be an integral part of epidemiologic studies on the health effects of air pollutants. Given that most people spend most of their time indoors and that indoor levels of pollutants can often exceed outdoor levels, exposure in the indoor environment can be an important component of total exposure.

Two other recently initiated projects will investigate ways of evaluating both indoor and total exposures for use in epidemiologic studies. In one (RP2159) subjects will carry small, personal CO monitors to determine their total exposure. Contributions from indoor and outdoor environments will be calculated on the basis of diaries kept by the participants. The other project (RP2265) will investigate NO_2 exposures for a population group by correlating the value ranges obtained from stationary outdoor monitors and from indoor monitors. The ability of indoor air quality models to provide data useful for epidemiologic studies will also be assessed.

Indoor air pollution research at EPRI has moved beyond the problem definition stage, in which indoor and outdoor concentrations were compared, to encompass several projects addressing specific questions about the indoor environment. These include questions about how pollutant concentrations in residences are affected by the interactions between indoor sources, outdoor concentrations, and building physical factors; the relative importance of indoor environment exposures in determining total exposure; and how indoor exposures of different population groups may best be categorized. The results will have application to programs in both energy conservation and human health. Future work will widen these efforts to include other building types and indoor exposure environments, with the ultimate goal of supporting risk-cost-benefit assessments that relate health risk to building type and energy use. *Project Managers: Robert M. Patterson and Gary G. Purcell*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

BETA BATTERY DEVELOPMENT

The beta battery is one of the new high-performance batteries under development for electric utility load leveling and for electric vehicle application (RP128). The beta battery system, operating at 300°C, is based on sodium and sulfur as reactants and is unique in that the electrolyte is solid and the electrodes are liquid. The solid electrolyte does not allow self-discharge, and there is no loss of electrolyte as occurs in aqueous systems.

Energy storage during off-peak periods is one of the more powerful tools available to utilities for economically and effectively meeting customers' power and energy requirements. Batteries are one of the options being considered for energy storage. If successfully developed, batteries could offer the utility industry several unique characteristics. They are modular, and they can be located in remote areas. They have fast electrical response for spinning reserve and system regulation, and they do not affect the environment. Of the battery systems under current investigation, that based on sodium, sulfur, and a solid electrolyte (beta alumina)—the beta battery—is of interest because it offers many of the characteristics desired in batteries. It can store energy with low battery weight; it uses low-cost materials; and it can operate at high (cyclic) efficiencies. Because of its high energy-to-weight ratio, the beta battery is also considered a prime candidate for use in electric vehicles. (For an account of beta battery development, see the *EPRI Journal,* March 1982, p. 52.)

During the past year, EPRI-funded work at General Electric Co., in cooperation with Chloride Silent Power, Ltd., (CSPL), has been highlighted by successes in technical areas that have been under investigation for several years. Foremost have been advances in cell life, reduction or elimination of increases in electrolyte resistance, and advances in the cell designed for utility use.

A persistent problem in battery development in past years has been the increase in electrolyte resistance with operating time. An increase in internal resistance seriously affects the cell performance because it not only changes the cell's electrical efficiency but tends to decrease the attainable watthour (amperehour) capacity. The rise in resistance was observed to be as high as 0.2% per cycle. Intensive study of factors influencing this phenomenon, including control of impurities and surface chemistry, has resulted in a reduced resistance rise to a very acceptable level of 0.01% per cycle. If trends in cell testing continue, increases in electrolyte resistance can be expected to be eliminated entirely.

This research into the chemistry of electrolyte resistance increase and into electrolyte composition, seal design, and production control improvements has significantly lengthened the life of beta alumina commercial-size cells. A statistically designed experiment now in progress at General Electric and CSPL indicates that the average cell life may have been increased by at least a factor of three to about 1500 cycles. The average life of cells must ultimately be increased to 4500 cycles to reduce future beta battery system replacement costs.

Cell life, and consequently battery life, is the focus of beta battery development. Figure 1 shows the improvements made and those planned. The lives of laboratory cells have lengthened from very short values to the present values above 2000 cycles. This increase has occurred in steps as research has identified and controlled various life-limiting factors. Using the results of these laboratory studies, researchers have tested

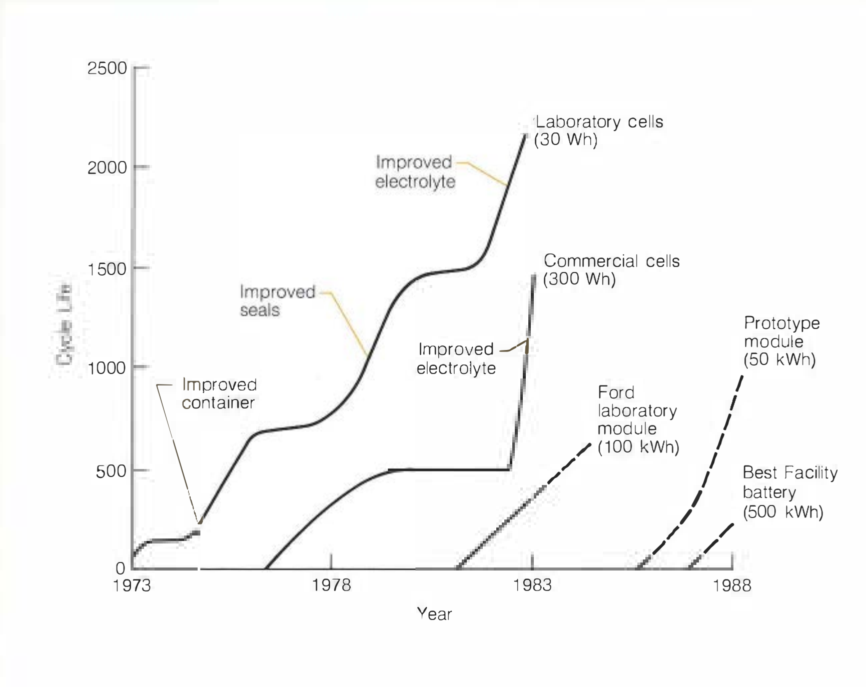


Figure 1 The progress of sodium-sulfur (beta) battery development. Progress with laboratory cells occurs in many steps, whereas progress with larger cells and batteries occurs more slowly but in large increments.

larger cells representative of commercial sizes. As the figure shows, life cycles have improved much more quickly, with the life of commercial 300-Wh cells now at 1500 cycles. Because of the recent advances in laboratory cells, observed lives of commercial cells are expected to rise again very quickly.

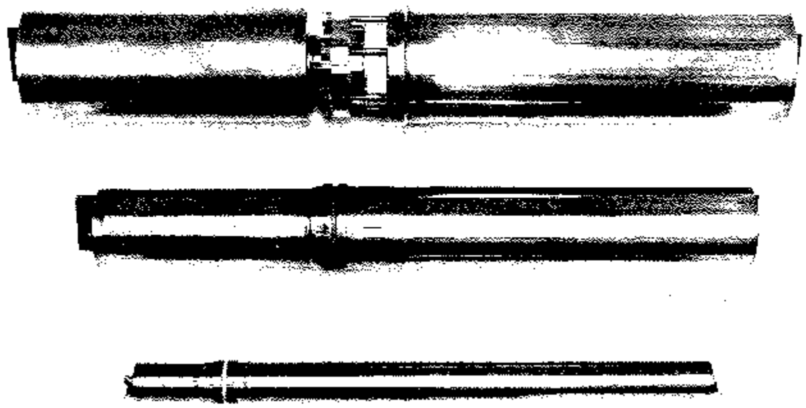
Under DOE sponsorship, Ford Aerospace and Communications Corp. is testing cell arrangements electrically configured as batteries. As Figure 1 shows, cell life is increasing. Plans, or goals, for prototype units and for the 500-kWh battery developed at the Battery Energy Storage Test (BEST) Facility are shown at the right of the figure.

Cells are being developed for various applications. Sizes range from laboratory cells of about 10-Ah capacity to those nearing 1000-Ah capacity. Figure 2 shows three cell sizes under study at Ford. The upper cell in the figure is a high-energy (850-Wh) cell designed for weekend charging and other applications where extended discharge times are useful, such as renewable energy systems based on sun and wind. The high-energy cell uses the same electrolyte size and operates within the same power range as the conventional utility cell, but for longer times. Under a cycle of a 40-hour discharge and a 40-hour charge, the cells of this design show an overall 85% energy efficiency. Present work in stationary energy storage is directed toward optimizing high-energy cell designs, as well as understanding their applicability to electric utility load leveling.

The middle cell in Figure 2 is the 250-Wh load-leveling cell, which operates under a cycle of a 5-hour discharge and a 7-hour charge. These cells were used to construct a 100-kWh battery of 512 cells (*EPRI Journal,* October 1981, pp. 6–13). Three of the original four battery submodules are still being tested after almost two years of operation. Data analysis indicates the characteristic cell life is almost four years. The fourth module was removed from the battery after 105 cycles because an equipment malfunction resulted in excessive current leakage.

The bottom cell in the photograph is designed for an electric vehicle. Cells of this type have demonstrated simultaneous steady-state values >180 W/kg and >120 Wh/kg. In addition to the high performance under steady-load conditions, the cells are capable of very high pulse power, even near the end of discharge. The EV cells can accept the amount of charge equivalent to the rated vehicle range in a half-hour. Even at high rates, the electrical efficiency of the cell remains high (80% at equal charge and discharge times of about 4 hours). Program efforts are now concentrated on fabrication of a vehicle battery for bench and in-vehicle testing.

Figure 2 Cells being studied by Ford Aerospace and Communications Corp.: (top) high-energy cell—460 Ah, 850 Wh, 85% efficiency, 40-h discharge, 40-h charge; (middle) Mark-II load-leveling cell—150 Ah, 250 Wh, 75% efficiency, 5-h discharge, 7-h charge; (bottom) EV cell—32.5 Ah, 66 Wh, 85% efficiency, 3-h charge, 3-h discharge.



Information necessary for beta battery improvements is obtained, in part, by analyzing cells after they have been subjected to various tests. As the number of larger cells being tested has increased and as their longevity has increased, thorough scientific data on tested cells' states have become increasingly important and difficult to obtain. Under a separately funded program, EPRI has made the posttest analysis facility of Argonne National Laboratory (ANL) available to the General Electric–CSPL effort.

Figure 3 shows the special resources available at ANL. Because the cells contain materials that react with atmospheric water vapor and oxygen and such reactions can obscure the evidence that would indicate unsuspected cell behavior, it is necessary to open tested cells in the inert and dry atmosphere provided by the dry boxes. These boxes contain facilities for cutting the cells open; preparing samples for metallurgical examination; and by using closed-circuit television, performing optical microscopy on the cell components as they are disassembled. These resources are part of the DOE battery project and are also available to Ford.

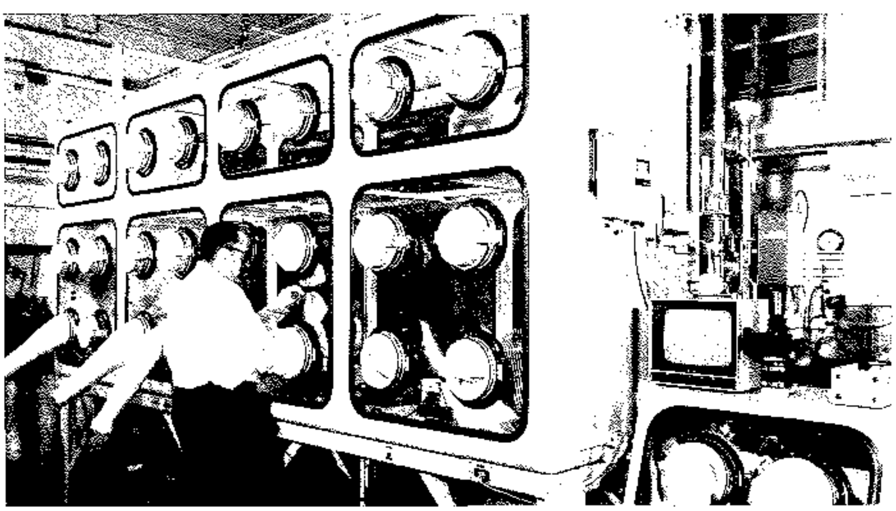


Figure 3 Posttest analysis facilities at Argonne National Laboratory provide the dry and inert atmosphere necessary for careful inspection of exercised beta cells.

Studies of the electrolyte composition itself are now adequate, and future work at General Electric will emphasize increasing cell reliability and life by improving quality control of all process variables. To augment quality control techniques and to investigate some special electrolyte alternatives, EPRI has recently begun a project with Ceramatec, Inc. Ceramatec will explore a quality control test of electrolyte composition by passing an ionic current through the electrolyte. The cell used does not employ sulfur but, rather, two sodium electrodes. In addition, Ceramatec will evaluate the manufacture of tougher electrolytes to improve strength and cell life.

To provide prototypes for utility load leveling remains the long-term goal for the EPRI beta battery project. The present objective is to test a 500-kWh unit in the BEST Facility during 1985–1987. An RFP for such a battery will be issued in late 1983. As support for this program, the selected contractor will test submodules in 1984. Work during 1983 at General Electric and CSPL will endeavor to improve quality control of all manufacturing steps and materials and develop the engineering studies necessary to design batteries from cells. A final report of the 1981 General Electric work is available (EM-2579). *Project Manager: Robert D. Weaver*

EPRI'S HYDRO R&D STRATEGY

Because incentives for hydroelectric power development and improvement have been increasing, EPRI is pursuing hydroelectric R&D—a subprogram established in 1981—with funding of $8 million for 1983–1987. Until recently, EPRI did little hydro research because the mature technology is extensively used and a number of public agencies are involved in hydro projects. However, hydroelectric output can be increased with EPRI-funded projects aimed at helping producers improve equipment procurement, system planning, and maintenance. The possible resulting incremental increase in the output of this country's 64 GW of conventional hydro and 13 GW of pumped-hydro plants produces a potential annual savings of nearly half a billion dollars.

With over a century of experience in generating electric power from hydroelectric plants, this nation's hydropower producers have a vast amount of information about the issues that face the industry, as well as approaches to their resolutions. EPRI has extensively tapped this resource to tabulate and rank the industry's needs.

- Define causes of, and means for reducing, forced outages. Although hydro plant availability is high (95% for conventional hydro and 85% for pumped hydro) compared with that of thermal power plants, cavitation damage, variable success of operating and maintenance procedures, inability to assess equipment degradation during operation, and certain peripheral equipment performance still remain problems.

- Reduce frequency of scheduled outages. Scheduled outages typically occur every two years and emphasize cavitation-damage monitoring and repair. A very few groups have managed to increase the cycle to once every four years by improving cavitation-damage repair procedures. However, standardized procedures have yet to be developed and made available to the entire industry. There are no diagnostic tools for in situ cavitation-damage monitoring, such as acoustic emission and frequency signature analysis, which could increase cycle time even further.

- Improve new equipment reliability. Reliability of some new plants has been poor. For example, the Bureau of Reclamation's 4000-MW plant No. 3 at Grand Coulee Dam and TVA's 1700-MW Raccoon Mountain pumped-hydro plant are taking 3–5 years to achieve routine operation after construction and installation. Average availability for both of these plants has been approximately 30%.

- Establish a coordinated effort to address environmental and safety concerns. Dams can change water quality, notably by dissolving metals, increasing sediment, influencing temperature fluctuation, supersaturating water with dissolved gases, and lowering dissolved oxygen levels. The controversy that surrounds these environmental effects delays, and in some cases prevents, dam construction and/or optimal plant operation. The collapse of the Teton dam exemplifies the importance of the safety issues. Although accidents of that nature are not common, dam failures among the world's 15,000 dams (excluding China) occur approximately once per year.

- Develop a standardized low-cost package for small hydro. Small hydro is often economically viable. However, today's common practice of developing a unique approach to each site, as is done for conventional large-hydro plants, increases costs and delays licensing.

- Define planning procedures that would correctly recognize hydroelectric generation benefits. Improvements in planning procedures are needed that better recognize such operating features as load following, system regulation, and spinning reserve, the value of which increases the competitiveness of hydroelectric generation and other energy storage options. The result would be that the industry would benefit through earlier and expanded use of hydro with storage and pumped hydro.

- Define methods for upgrading existing plants to increase output. Many hydro plants are relatively old and in need of improvement to restore full output. In addition, the absence of simple, standardized monitoring means that many plants run at less than optimal capacity and energy output.

In many cases, individual utilities and power producers have successfully addressed these needs. National adoption of these solutions, however, has been hampered to some extent by their apparent regional or plant-specific nature and to a larger extent by the lack of information exchange, particularly between private and public power producers. Therefore, EPRI's basic R&D program emphasizes information exchange, coordination, and working groups. Hydroelectric power producers have encouraged EPRI to play a lead role in this activity—a role EPRI is uniquely qualified for and able to play. For example, among EPRI's most important activities are (1) survey, integration, and periodic dissemination of information and accomplishments of hydropower producers that will be directly useful to others in the field, and (2) seminars and workshops for the exchange of up-to-date information and techniques of effective operation and maintenance of hydro plants. Two such workshops—one in Atlanta, Georgia, in November 1982 and the other in San Francisco, California, in February 1983—were very successful. Nearly 300 people representing over 100 different hydropower producers participated.

A key to the hydroelectric R&D subprogram's success has been EPRI's close coordination with utilities and public power producers, which was formalized in mid 1982 with the establishment of the EPRI Hydro Working Group. This group represents all segments of hydropower production with respect to ownership, location, position, and discipline, and it guides EPRI planning and implementation of hydro projects.

EPRI has initiated and the Hydro Working Group has endorsed work in the following areas.

- Developing small-hydro sites by standardizing and demonstrating modular equipment packages, developing improved procedures for site evaluation, and relaying the experiences of ongoing site-development projects, particularly the 20 DOE projects

- Improving availability by reducing forced and scheduled outages through expanded industry information exchange programs, new diagnostic tools for evaluating equipment degradation, better cavitation-damage repair procedures, and improved equipment

- Expanding hydro output by improving availability and recognizing operational benefits, which requires use of improved planning tools and acceptance of real-time flow measurement devices

Table 1 lists specific projects in these areas and their approximate cost. Over the next two years EPRI's hydro activity is expected to grow to include the following activities: evaluation of methods to monitor and control the environmental effects of hydroelectric plants, particularly with regard to dissolved gases, fish screens, and downstream fish migrations; improvement of equipment procurement by better model evaluation and preparation of a specifications manual for equipment procurement; and evaluation of approaches to monitor dam performance and improve dam safety. EPRI is also considering an effort to augment a national or international model-test facility to achieve sufficient flexibility and capability for use by utilities to determine future turbine performance.

Estimating R&D benefits is always a difficult job. However, since the bulk of EPRI's hydro R&D work emphasizes incremental improvements in existing plants, order-of-magnitude cost-savings projections are achievable. Table 2 summarizes specific benefits and national savings. It shows that incremental improvements in equipment procurement, planning, and maintenance, when applied nationally, yield nearly a half a billion dollars in annual savings.

Realizing these potential benefits requires both successful R&D and the ability to transfer the results to industry. Successful research is probably easier to achieve because it focuses on a few key areas and there is little risk associated with the outcome. Sharing experiences among hydropower producers can also have significant benefits. Successes achieved by some utilities are likely to be achieved by other utilities. However, successful technology transfer is difficult because of hydroelectric power's complex infrastructure. Thousands of people from federal agencies, public and private utilities, and third-party developers are employed in hydro planning, design, construction, operation, and maintenance.

Improvements in hydro R&D are achieved in large part by better purchasing, operating, and maintenance procedures, as well as minor technologic changes. In addition to funds (which are virtually insignificant), they require the power producers' commitment to gather information, to digest its applicability, and to implement changes in long-standing industry practices. When money is tight, these activities may seem superfluous, but, in fact, the savings are real and substantial, as the figures clearly demonstrate. EPRI encourages active involvement in its information exchange programs by the country's hydropower producers. *Program Manager: J. R. Birk*

Table 1
ONGOING HYDRO R&D PROJECTS

Type	Project	Cost ($000)
Small hydro	Study cost and design of standardized, prefabricated modular concepts for small hydro	300
	Demonstrate previous concept	1250
	Publish procedures manual (2d ed.) for site screening	30
	Relay experiences from DOE demonstrations (20) and other completed projects	50*
Plant availability	Conduct O&M conferences	225
	Assess capability to identify and evaluate causes of forced outage	300
	Publish cavitation-damage review and repair procedures manual	250
	Develop vibration signature analysis tools for turbomachinery problems	(tbd)
	Correlate model test data with prototype field performance	1200
Plant output and others	Standardize real-time flow measurement tools	500
	Conduct planning optimization workshop	100
	Assist Oak Ridge National Laboratory and DOE in headwater benefits study	30
	Survey and integrate information from hydropower producers	500

*Plus $300,000 from DOE.

Table 2
BENEFITS AND SAVINGS FROM EPRI'S HYDRO R&D

Category	Specific Benefit	Potential National Savings ($ million/year)
Small hydro	$200/kW cost decrease	20
Availability	1% improvement	150
New equipment	3-year decrease in plant commissioning time for 25% of new plants	70
Plant output	0.5% efficiency increase	75
Increased use of resource	4 GW additional expansion of hydro resource over next 20 years through improved planning and environmental impact	150
Total		465

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

CONTROLLING PWR RADIATION FIELDS

Reducing the radiation exposure of nuclear plant workers is a goal of the U.S. electric power industry. Because radiation fields outside the reactor core are the source of most of the exposure, EPRI's approach to the problem is aimed at controlling these fields. PWR work has centered on identifying and developing effective plant radiation control practices, including primary-system chemistry specification, replacement of cobalt sources, and decontamination.

Radioactive contamination arises because corrosion products from the primary system deposit or precipitate in the reactor core and become activated. Some of these radioactive deposits are redissolved or resuspended in the coolant and then deposit on out-of-core surfaces, rendering those areas radioactive. Cobalt-60, which is produced by the activation of nonradioactive cobalt from plant materials, is responsible for 80% of the radiation exposure of plant workers during operation, inspection, and maintenance tasks.

EPRI's program for reducing PWR radiation fields focuses on three parts of the field buildup process. The goals are to reduce cobalt sources by changes in materials specification, to reduce corrosion-product transport by chemistry control, and to remove deposited radioactive oxides by decontamination. Work to identify and replace sources of cobalt was described in an earlier R&D status report (*EPRI Journal*, June 1982, p. 58). This report addresses the other two research areas, specification of primary-system chemistry and chemical decontamination.

Coolant chemistry specification

Control of the primary-system chemistry is essential if crud formation on the fuel and subsequent redeposition of radioactive oxides outside the core are to be minimized. EPRI's efforts in this area include the establishment of a data base for Westinghouse Electric Corp. plants through a standard radiation-field monitoring program, fundamental studies to determine the key factors affecting crud transport, and in-plant comparisons of different chemical regimes.

An important subject of investigation is the influence of pH on corrosion-product transport. In PWRs the coolant pH is continually changing during the fuel cycle because boric acid is used as a chemical shim; lithium hydroxide is added to the coolant to control pH. Laboratory studies at Clarkson College (RP966) have shown that the formation and stability of colloidal corrosion products are strongly affected by pH, and that the adsorption of cobalt on colloidal iron oxides is greatly increased at high pH. The effects of pH on corrosion-product solubility have been calculated by Babcock & Wilcox Co. (RP825-1). Cobalt solubility is greatest at low pH values (high boron, low lithium) and also increases above the minimum at very high pH values (low boron, high lithium).

The complex interaction between pH and temperature effects suggests that the best way to minimize changes in cobalt solubility, and hence crud transport, is to maintain a constant, relatively high pH throughout the PWR fuel cycle. To achieve a high pH, it is necessary to use more lithium hydroxide than often used in the past. However, because the boric acid concentration decreases during a fuel cycle, resulting in lower acidity, the amount of lithium hydroxide must also be

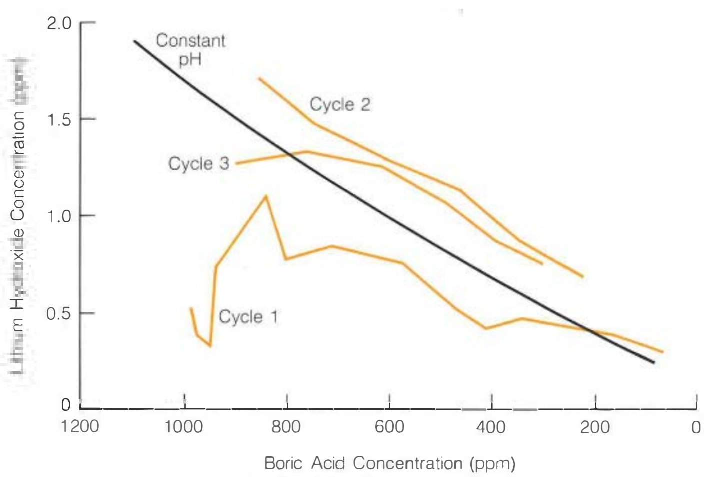


Figure 1 Primary-system chemistry in the first three fuel cycles at the Trojan PWR. Boric acid is used for reactivity control and lithium hydroxide for pH control. The boric acid concentration decreases during a fuel cycle. By coordinating the lithium hydroxide concentration with that of the boric acid throughout a cycle to maintain an approximately constant pH—as in cycles 2 and 3 here—fuel crud formation and transport can be reduced.

reduced as the cycle progresses in order to maintain a constant pH. (Minimizing corrosion-product transport is more difficult in PWRs than in CANDU plants, which do not use a boric acid chemical shim. Radiation fields in CANDU plants are low.)

The benefits of pH control were clearly demonstrated in a three-cycle chemistry test conducted by Westinghouse at the Trojan plant of Portland General Electric Co. (RP825-2). In the first fuel cycle the pH was low and variable, with a lithium hydroxide concentration of 0.3–1.0 ppm (Figure 1). The results were heavy fuel deposits and high out-of-core radiation fields (Figure 2). The second and third cycles featured coordinated lithium-boron chemistry control. Higher lithium hydroxide concentrations were used, but the concentration was steadily decreased in each cycle to produce approximately constant pH. Extremely thin deposits formed on new fuel loaded after the first cycle, although crud on the remaining cycle 1 fuel decreased only slightly. The decreases in radiation fields observed in cycles 2 and 3 were small because of the hysteresis effect resulting from the 5.2-year half-life of the cobalt-60 deposited in cycle 1. Although this suggests that the full benefits of adopting coordinated chemistry control will take several years to be achieved, the observed decay in cobalt-58 (which has a 71-day half-life) on pipework gives an indication of the potential radiation-field reductions in the longer term.

Data on steam generator channel head radiation dose rates are being collected by Westinghouse, and a correlation between low dose rates and good coolant chemistry conditions (i.e., a constant, relatively high pH) is beginning to become apparent despite the hysteresis effect. It is clear that radiation-field buildup in PWRs can be reduced through pH control.

An international meeting on PWR radiation control sponsored by EPRI in September 1982 highlighted the importance of chemistry specification. Most PWR operators in Europe and Japan are now using coordinated lithium-boron control to maintain near-constant pH in their plants. Further EPRI work is aimed at optimizing the coolant chemistry to reduce the radiation-field buildup rate to the minimum value achievable.

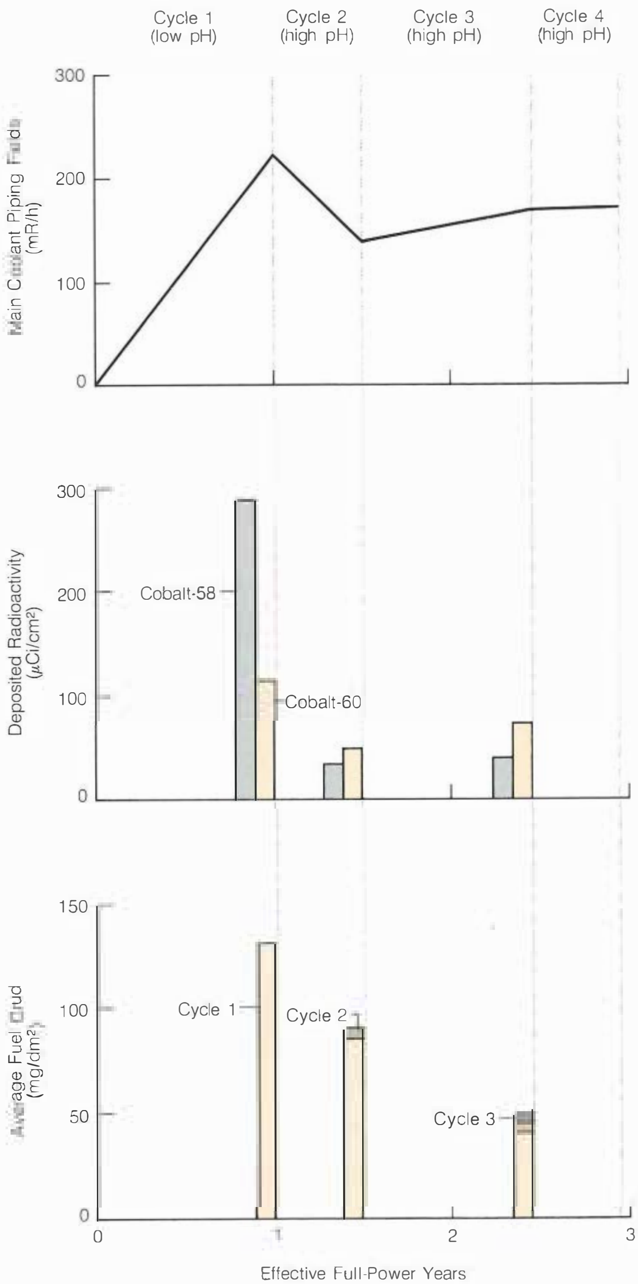


Figure 2 Effects of coolant pH on fuel crud formation and piping radiation fields at the Trojan PWR. (Total crud is averaged over the entire core surface, and the contribution from fuel loaded in each cycle is indicated.) Fuel crud deposits, the source of out-of-core contamination, were much thinner in cycles 2 and 3 (near-constant, higher pH) than in cycle 1. The piping fields also decreased in the later cycles—though not dramatically, because of the long half-life of cobalt-60, the main field contributor. The potential long-term benefits of pH control are suggested by the significant drop in cobalt-58 radiation and by the leveling off of the fields in cycle 4.

Decontamination

Nonchemical decontamination techniques—for example, grit slurries and high-pressure water sprays—have been evaluated for cleanup applications at Three Mile Island-2 (NP-2960), and many of these techniques are used at operating plants. However, the main thrust of EPRI's decontamination work has been the development and qualification of chemical techniques using dilute solutions for application to all or part of the primary system. Part-system decontamination is the most effective method of reducing the radiation exposure of personnel during steam generator repairs. Chemical cleaning of the entire primary system with the fuel in place achieves the longest-lasting effects because it removes fuel crud, the main source of subsequent recontamination.

EPRI has been in the forefront of dilute chemical decontamination studies through work at Battelle, Pacific Northwest Laboratories (RP828) and at the Central Electricity Generating Board's Berkeley Nuclear Laboratories in the United Kingdom (RP1329). From the latter project emerged the LOMI (low oxidation-state metal ion) reagent for removing radioactive corrosion products. LOMI reagents provide rapid dissolution through the reduction of corrosion-product oxides, with minimal corrosion of the underlying metal. The dissolved radioactive waste is removed by using conventional ion-exchange technology.

The LOMI system has been applied extensively in routine decontaminations of the United Kingdom Atomic Energy Authority's pressure-tube BWR at Winfrith. These decontaminations have been carried out with the fuel in place. Subsequent operation has shown no adverse effects on fuel performance. The Winfrith fuel materials are similar to LWR fuel materials, and these results indicate that the LOMI system could be used for LWR fuel cleaning. Overall, the LOMI reagents produced higher decontamination factors and much less corrosion than the strong citric and oxalic acid system employed previously by the UKAEA for 10 years.

Work at Battelle-Northwest (RP828) has determined the structure and composition of radioactive oxides on BWR and PWR materials. The Battelle studies and other work by Westinghouse (RP825-2) identified high-chromium spinel oxides (rather than the nickel ferrite found in fuel crud) as the main component of films on PWR out-of-core surfaces. Whereas the magnetite and hematite oxides in BWRs are extremely susceptible to LOMI reagents, these PWR corrosion products are not so readily dissolved in the vanadous picolinate and formate LOMI system used at Winfrith.

For PWR applications a readily available oxidizing reagent, such as dilute permanganate solution, is used to lower the chromium content of the radioactive films before the LOMI treatment. This combination of established technologies has been shown by the Central Electricity Generating Board to be effective on all steam generator materials. The technique has also been used to clean one channel head of the steam generator that was removed from Virginia Electric and Power Co.'s Surry plant in 1979. Quadrex Corp. performed this decontamination at Battelle-Northwest in November 1982 as part of the NRC-directed examination of the steam generator. Acid and alkaline oxidizing steps were coupled with the use of the vanadous picolinate and formate LOMI reagent. Good decontamination of both stainless steel and Inconel was achieved, and radiation fields were reduced by a factor of 10.

This field test showed that effective steam generator decontamination can be achieved by using the proven LOMI technology in combination with conventional oxidizing reagents. Future EPRI work in this area will focus on the qualification of decontamination technology for routine utility use, including materials testing and plant demonstrations of advanced decontamination techniques.

Implementation

The status of radiation control technology is shown in Table 1. For plants requiring steam generator work, channel head decontamination is available; its application has an immediate impact on radiation exposure. In new plants the use of chemistry control from startup will show significant benefits in slowing radiation-field buildup in the first year or so of operation. For older plants, however, the full benefits of this technique will take longer to realize. With a few exceptions, such as valves that require frequent reseating, cobalt replacement is mainly an option for new plants or for components requiring maintenance, repair, or periodic replacement (e.g., fuel assemblies). The use of low-cobalt Inconel in steam generator replacement and retubing could have a considerable impact on subsequent radiation-field buildup. *Program Manager: Christopher J. Wood*

PIPE INTEGRITY ANALYSIS

This report describes the status of the pipe integrity tasks of the research program on intergranular stress corrosion cracking (IGSCC) sponsored jointly by EPRI and the Boiling Water Reactor Owners Group (BWROG). These tasks assess if and when repairs are required in an austenitic stainless steel recirculation piping system after identification of IGSCC. The work addresses both the margin of safety and the economic considerations involved in planning for a pipe repair outage. Such planning requires determination of critical crack size (i.e., the size at which pipe failure is to be expected), prediction of the time necessary for the stress corrosion crack to reach this critical size, assurance that leakage and not pipe severance is the failure mechanism, determination of crack-opening areas and flow rates, and development of backup instrumentation for sensing and measuring leakage. The pipe integrity tasks have pro-

Table 1
STATUS OF PWR RADIATION-FIELD CONTROL TECHNIQUES

Technique	Status	Time Scale of Benefits
Part-system decontamination	Technology demonstrated	Immediate benefits
Complete-system decontamination (including fuel)	Field test planned for 1983–1984; full-scale demonstration to follow in four years	Greatest impact on doses, but technology unlikely to be proven before 1988
Primary-system chemistry (pH) control	In widespread use abroad; beneficial effects demonstrated	For new plants, significant reduction in field buildup rate predicted; for old plants, short-term reduction in buildup rate, with slow decline in fields predicted over longer term
Use of low-cobalt Inconel	Available for new plants and steam generator retubing and replacement	Longer-term effects on field buildup rate predicted
Use of low-cobalt hardfacing alloys	Under test for PWR applications; already in use abroad	Longer-term benefits; main impact in new plants

ceeded on schedule and are essentially complete. Final reports address the above issues, and modification of Section XI of the ASME Boiler and Pressure Vessel Code was approved March 11, 1983.

Critical crack size

Research in the BWROG program has shown that plastic collapse of the net section is the appropriate failure mechanism for circumferentially flawed stainless steel piping. Failure occurs when the net section (reduced by the crack) forms a plastic hinge. For bending loads, the analysis is reduced to simple beam theory. This finding is remarkable in that flaw analysis does not require fracture mechanics considerations.

Failure analysis diagrams for circumferential cracks have been derived on the basis of this net-section criterion. The diagrams were computed from membrane and bending equilibrium conditions across the plastic net section of the pipe. Together with the application of appropriate safety factors, these diagrams form the basis for new criteria on acceptance flaw size that have been proposed for Section XI of the ASME Code. (Acceptance flaw size is the maximum size at which a detected flaw can be allowed to remain without repair.) Table 2 presents the proposed acceptance flaw sizes for ASME Code level A and B loading conditions. It may be compared with Table IWB-3514-2 of Section XI of the code, which allows a maximum flaw depth of about 10% of the pipe wall thickness.

Details on this methodology are given in NP-2472; supporting information is presented in NP-2347 and the final report for RPT118-8. With the exception of code implementation, work on the definition of critical crack size is complete.

Table 2
ACCEPTANCE FLAW SIZE FOR NORMAL CONDITIONS
(crack depth as a fraction of wall thickness)

	Ratio of Crack Length to Pipe Circumference				
Stress Ratio*	0.1	0.2	0.3	0.4	≥0.5
1.4	0.40	0.21	0.15	†	†
1.2	0.75	0.56	0.40	0.32	0.27
1.0	0.75	0.75	0.63	0.51	0.41
0.8	0.75	0.75	0.75	0.68	0.53
≤0.6	0.75	0.75	0.75	0.75	0.63

*Ratio of the sum of the primary membrane stress and the primary bending stress to the code-allowable design stress, with a safety factor of 3.

†Governed by allowable flaw standards (~0.10) in ASME Boiler and Pressure Vessel Code, Section XI, Table IWB-3514-2.

Crack growth

The work described above addressed critical crack size with no discussion of subcritical growth due to stress corrosion cracking. Fatigue crack growth for ferritic steel is treated in Appendix A of Section XI of the ASME Code, but the code contains no guidance for IGSCC. RPT118-1 has developed a procedure for predicting crack growth that, when used with the critical flaw size methodology discussed above, may allow the deferral of pipe repair until it will have minimal impact on plant availability.

The research has shown that crack propagation rates are strongly influenced by the residual stress distribution normal to a circumferential crack. Extensive data are now available on the magnitude of these stresses. With these data and small-specimen data on crack growth rate as a function of stress intensity under BWR water chemistry conditions, it is possible to predict crack growth.

Predictions made in this way confirm that crack propagation in as-welded small-diameter lines is sufficiently fast that immediate repair is recommended if IGSCC is detected by in-service inspection. However, pipes with a diameter greater than 16 in (41 cm) have more favorable welding residual stress distributions. A crack growing in the tensile stress field on the inside of such a large-diameter pipe tends to arrest in a compressive zone deeper in the pipe wall; thus, periods on the order of years are necessary for a small crack to grow to a depth at which the remaining safety margin would be unacceptable. As a result, repairs in large lines may be deferred until scheduled refueling outages in order to minimize plant downtime.

This work is described in NP-2472. It is complete except for a test of a flawed 16-in-diam (41-cm) pipe to check the methodology. Tests to date verify the crack growth model.

Leak-before-break behavior

Under normal service loads, IGSCC in heat-affected zones near welds will result in leak-before-break behavior. A complete circumferential crack can exceed 50% of the wall thickness for the service loads to extend the crack by ductile tearing. Before the cracked area reaches this size, the azimuthal variations of welding residual stress and material susceptibility in the heat-affected zone, combined with the applied bending loads, will lead to asymmetrical crack growth and the formation of a through-wall crack. This hypothesis is borne out by extensive field experience.

A more important issue involves the safety margin of a cracked pipe and the potential for break-before-leak behavior in the event of abnormal displacements (resulting, for example, from a strong earthquake). Larger margins of safety are available if the loads are governed by prescribed displacement or rotation instead of applied forces or moments. With prescribed displacement there is relaxation of crack-tip stress with stable crack growth and the structure can sustain loads beyond the maximum load. Work in the BWROG program has shown that in most stainless steel piping it is impossible to have unstable circumferential crack growth at loads exceeding ASME Code level D faulted conditions; in these systems large plastic deformation, not guillotine pipe breaks, will occur.

A tearing instability analysis developed in NRC research has shown how increased piping system compliance reduces the amount of stable crack growth. When the unsupported pipe length is longer, more elastic energy is available under load to feed into the plastic net section containing a crack and drive the crack unstably. The increased compliance makes the system loading mechanism appear to be closer to (dead) load control than displacement control. The NRC work showed that if the ratio of pipe length to radius is less than a dimensionless material property called the tearing modulus (T_m), instability is impossible. Taking T_m as 200 for stainless steel, the critical unsupported length of a 2-ft-diam (61-cm) pipe is

200 ft (61 m), a length that is unlikely in nuclear power plants.

RPT118-9 applied this tearing instability theory to primary and secondary piping runs in existing nuclear power plants. The analysis showed that it is impossible for ASME Code level D loads to cause guillotine pipe breaks in the austenitic piping runs considered.

Also investigated was the stability of an elliptical surface flaw in both the radial and the circumferential direction. The objective was to determine if, when a surface crack breaks through the pipe wall, the crack will continue to propagate circumferentially and lead to a guillotine break. Results from these analyses were used in leak-before-break diagrams, in which the axes define crack geometry and a curve separates leak and break geometries. The large displacements required for instability suggest the probability of circumferential instability is very low.

The piping instability analyses are reported in NP-2261. More information on instability analysis using the estimation methods of the EPRI plastic fracture handbook (NP-1931) is given in the final report for project RPT118-8. The leak-before-break diagrams are presented in NP-2347.

Crack-opening area and flow rates

Defense-in-depth requires that pipe leakage be detected and measured in situ by suitable instrumentation. Analytic work in the BWROG program has led to the development of methods for predicting crack-opening areas and the resulting flow rates. Experimental work has produced data on the minimum flow rate detectable by commercial acoustic sensors and on the correlation of acoustic energy with flow rate.

Simple techniques for estimating the crack-opening area and flow rate for circumferential through-wall cracks have been developed (NP-2472, Volume 2, Appendix D). Using BWR conditions, calculations were made to compare the crack length required for a flow rate of 5 gal/min (0.0003 m^3/s) with the critical crack length. This flow rate is the maximum unidentified leakage rate allowed in nuclear power plants. Experimental work has shown the 5-gal/min rate to be 100 times greater than that detectable by acoustic sensors located near a crack. Table 3 shows that the critical crack size is always larger than that for a 5-gal/min flow rate. Data in Table 3 assume normal operating conditions, with a pressure stress across the crack of $S_m/2$. S_m is the code-allowable design stress.

Table 3
COMPARISON OF CRACK LENGTHS
(inches)

Pipe size (Schedule 80)	4	10	24
Crack length for 5 gal/min flow	4.50	4.86	4.97
Critical crack length	6.54	15.95	35.79

In another effort (RPT118-8), the engineering analysis methods of the EPRI plastic fracture handbook have been used to derive diagrams of load (or applied moment) and end deflection versus crack-opening area for the large loads associated with faulted conditions that cause extensive local deformation. These diagrams illustrate the extent to which crack size, pipe length, and type of loading affect the magnitude of the crack-opening area of through-wall flaws.

In a third effort an analytic model of flow through tight stress corrosion cracks has been validated, and the acoustic spectra associated with this flow have been measured for use in flow detection systems. Researchers have experimentally determined the minimum detectable flow rate through a stress corrosion crack and have obtained the data needed to assess the ability of on-pipe acoustic sensors to correlate measured acoustic energy with flow rate. Three different acoustic transducers have been evaluated in on-pipe arrays designed to check geometric attenuation. This flow instrumentation work is described in a topical report for project RPT118-2 (forthcoming).

Application of pipe integrity analysis

Continued plant operation in cases where coolant lines have IGSCC defects is possible if analysis shows that the flaw has no significant consequences for plant safety. It is necessary to demonstrate that the safety margin of the flawed piping is adequately large, and that if failure were to result from some unforeseen overload, it would take the form of a stable leak rather than a catastrophic fracture. It is also necessary to determine leak rates through the cracks and the consequences of such leaks. Methods for considering these questions were addressed in the BWROG program and were approved by the Main Committee for implementation in the ASME Boiler and Pressure Vessel Code. *Project Managers: Douglas Norris and Theodore Marston*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP990-8	Data Systems/R&D Evaluation for Power Generation	5 months	60.9	Fern Engineering *R. Duncan*
RP1187-10	Benefits of Improved Gas Turbine Reliability	8 months	99.9	Power Technologies, Inc. *C. Dohner*
RP1197-6	Cerro Prieto Field Test of Upstream Reboiler	7 months	63.9	Instituto Investigaciones Eléctricas *E. Hughes*
RP1348-15	Strategies for Advanced Photovoltaic Research	8 months	99.5	Strategies Unlimited *E. DeMeo*
RP1654-18	Long-Term Leaching of Coal Gasification Slag	42 months	47.4	Radian Corp. *J. McDaniel*
RP1926-3	Survey and Analysis of Steam Plant Problems in Gas Turbine-Combined-Cycle Power Plants and Their Influence on Reliability	9 months	55.0	Solar Turbines, Inc. *R. Duncan*
RP1971-9	Plans for Selected Engineering Opportunities Experiments in Fusion Technology	7 months	147.1	Rockwell International Corp. *K. Billman*
RP1996-6	Goodnoe Hills MOD-2 Cluster Test Program	3 months	147.4	Boeing Engineering & Construction *F. Goodman*
Coal Combustion Systems				
RP983-13	CONAC Test Plan	3 months	52.6	Bechtel Group, Inc. *F. Karlson*
RP1257-4	Cosponsorship Agreement for Urban Scrubber Development With Resox	10 months	200.0	Consolidated Edison Co. of New York, Inc. *T. Morasky*
RP1261-9	Assessment of Recirculated-Cooling-Water Test Program	5 months	49.6	Water General Corp. *W. Chow*
RP1263-10	Portable Infrared Field Monitor for PCBs	9 months	50.0	C/S Associates, Inc. *R. Komai*
RP1263-12	Arc Pyrolysis for PCB Capacitor Destruction, Phases 1 and 2	4 months	94.6	Electro-Petroleum, Inc. *R. Komai*
RP1263-14	Revision of PCB Disposal Manual	9 months	99.8	SCS Engineers *R. Komai*
RP1263-16	Application of Biotechnology to PCB Disposal Problems	5 months	48.8	Leland D. Attaway & Associates *R. Komai*
RP1403-6	Assessment of Supercritical Power Plant Operation	16 months	29.0	Ebasco Services, Inc. *A. Armor*
RP1404-4	Commercial Cost Estimates and Financial Evaluation: Metal Recovery From Fly Ash	8 months	150.0	Kaiser Engineers, Inc. *D. Golden*
RP1689-8	Recommended Operation and Maintenance Guidelines for Steam Surface Condensers	2 years	147.9	Heat Exchanger Systems, Inc. *I. Diaz-Tous*
RP1711-2	Root Cause Analysis: Availability and Plant Performance Problems	20 months	327.1	Southern Company Services, Inc. *A. Armor*
Electrical Systems				
RP1281-6	Field Evaluation of Polysil Insulators	16 months	77.0	Pennsylvania Power & Light Co. *J. Dunlap*
RP1471-2	Fumigant Effectiveness in Creosote- and Penta-Treated Southern Pine Poles	3 years	86.1	Research Foundation of State University of New York *R. Tackaberry*
RP1536-9	Electrochemistry of the Depletion of DCA48 in Freon	10 months	126.8	General Electric Co. *V. Tahiliani*
RP1592-1	Amorphous Steel Core Distribution Transformer	2 years	5049.0	General Electric Co. *R. Tackaberry*
RP1605-2	Grout Delivery System	16 months	284.7	Kinnan & Associates *P. Landers*
RP1902-2	Transmission Line Interference With Railroads and Pipelines	22 months	298.7	Science Applications, Inc. *J. Dunlap*
RP1917-2	Data Transfer and Conversion	14 months	315.8	Boeing Computer Services, Inc. *J. Lamont*
Energy Analysis and Environment				
RP863-5	Price Elasticity of Electricity Demand	5 months	50.0	Department of Energy *A. Faruqui*
RP1795-2	Artifact Problems in Sampling Airborne Organics	8 months	67.0	Environmental Research & Technology, Inc. *J. Guertin*
RP1816-3	Sample Design for Load Research	17 months	140.0	Applied Management Sciences, Inc. *E. Beardsworth*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1826-11	Decision Framework for PCB Control Strategies	13 months	41.8	Decision Focus, Inc. *A. Silvers*
RP1947-8	Technical Transfer of Fuel Management Models	10 months	50.0	Mistina *S. Chapel*
RP1988-3	Long-Term-Shortage Cost Analysis	16 months	270.1	ICF Incorporated *A. Halter*
RP2074-3	U.S. Generating Capacity Margins	6 months	45.0	Strategic Decisions Group *D. Geraghty*
RP2198-2	Leaching Studies of Utility Solid Wastes	13 months	354.2	Arthur D. Little, Inc. *I. Murarka*
RP2222-1	Occupational Toxicology of Chemicals in the Utility Workplace	2 years	486.1	Dynamic Corp. *W. Weyzen*
RP2265-1	Exposure to Nitrogen Dioxide of Inner City Residents in New York City	15 months	123.0	Columbia University *C. Young*
RP2300-2	Feasibility of Condenser-Targeted Chlorination System	8 months	85.0	Stone & Webster Engineering Corp. *M. Miller* *W. Chow*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1136-18	EV Component Testing and Development, TVA Phase 3	1 year	655.0	Tennessee Valley Authority *B. Askew*
RP1464-3	Retrofitting Large Power Plant Motors for Adjustable Speed: Opportunities, Techniques, and Costs	6 months	93.2	Bechtel Group, Inc. *R. Ferraro*
RP1791-15	Field Evaluation of Compressed-Air Energy Storage Within an Aquifer	16 months	1182.8	PB–KBB, Inc. *R. Schainker*
RP1940-5	Survey of Heat Pump Field Performance Data	4 months	37.9	Synergic Resources Corp. *A. Lannus*
RP1965-2	Utility Process Application Conference	1 year	60.9	Energy Management Consultants *L. Harry*
RP1968-2	Microcomputer Control Applications in Industry	10 months	29.9	University of South Florida *J. Brushwood*
RP2033-1	Advanced Central Heat Pump Development	56 months	2925.0	Carrier Corp. *J. Calm*
RP2033-10	Compressor Improvements for Heat Pumps	13 months	276.0	Brookhaven National Laboratory *J. Calm*
RP2033-13	Heat Exchanger Requirements for Potable Water Protection	6 months	70.7	Fauske & Associates, Inc. *J. Calm*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1442-6	BWR Power Shape Monitoring System Support	10 months	128.1	Systems Control, Inc. *A. Long*
RP1542-6	Decision Analysis Applied to Structural Mechanics	10 months	122.0	Strategic Decisions Group *S. Tagart*
RP1544-12	Consulting Activities at TMI-2	1 year	79.6	Newport News Industrial Corp. *A. Roberts*
RP1544-14	Development of a Remote Scanner	10 months	69.1	Science Applications, Inc. *K. Winkleblack*
RP1557-6	Radionuclide Correlations in Low-Level Radwaste, Phase 1	3 months	76.7	EDS Nuclear, Inc. *M. Naughton*
RP1560-3	Environmental Release of Iron-55 and Similar Radionuclides	1 year	96.4	Science Applications, Inc. *M. Naughton*
RP1571-7	Spectroscopic Characterization Methods for pH Control Agents	9 months	106.7	Westinghouse Electric Corp. *T. Passell*
RP1757-17	Dominance of Hutchinson-Rice-Rosengren Singularity and Application to Safety Margin Assessment of Pressure Vessel and Piping	14 months	30.0	Brown University *D. Norris*
RP1761-20	Development of BNC Spare-Time Kinetics Computer Code	1 year	116.0	Tennessee Valley Authority *P. Bailey*
RP1761-21	RASP Distribution	6 months	25.0	University Computing Co. *L. Agee*
RP1929-12	Crack Propagation in Turbine Steels	23 months	517.2	The Metal Properties Council, Inc. *A. Giannuzzi*
RP2056-3	Work Plan for Assistance to EPRI in Selecting Its Research Strategy at TMI	6 months	96.7	Strategic Decisions Group *S. Tagart*
RP2142-1	Allowed Downtime Theory and Strategy Development	28 months	209.9	Battelle, Columbus Laboratories *B. Chu*
RP2157-1	Steam Generator Project	4 years	1000.0	Battelle, Pacific Northwest Laboratories *J. Mundis*
RP2160-2	Determination of Thermodynamic Data for Modeling Corrosion	22 months	174.5	Brigham Young University *M. Angwin*
RP2164-4	Signal Processing for Underclad Crack Detection	1 year	264.7	Tetra Tech, Inc. *J. Quinn*
RP2165-3	Evaluation of UDRPS	6 months	164.1	Dynacon Systems, Inc. *J. Quinn*

New Technical Reports

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

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

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of all EPRI reports on request. Microfiche copies are also available from Research Reports Center, at the address given above. The price per volume of $6.00 in the United States, Canada, and Mexico and $12.00 per volume overseas includes first-class postage.

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ADVANCED POWER SYSTEMS

Proceedings of the Sixth Annual Geothermal Conference and Workshop

AP-2760 Proceedings (WS82-118); $23.50

This record of the EPRI-sponsored Sixth Annual Geothermal Conference and Workshop (held June 28–July 1, 1982, in Snowbird, Utah) presents reviews of EPRI geothermal research projects, utility projects and plans, and worldwide geothermal power development. Accounts of workshop discussions, which focused on how to shorten the time to power on-line, are included. The contractor is Altas Corp. *EPRI Project Manager: V. W. Roberts*

Coal Liquefaction Studies

AP-2779 Final Report (RP779-23, RP2210-1); $31.00

This report describes the methods and procedures developed to produce No. 6 fuel oil from solvent-refined coal (SRC). It discusses the addition of distillate cutter stock and the solvent extraction of SRC to achieve the target fuel oil viscosity; attempts to increase the distillate product yield by catalytically hydrotreating SRC; and simulated two-stage coal liquefaction experiments performed in batch reactors to further increase the distillate yield. The contractor is the University of Wyoming. *EPRI Project Manager: N. C. Stewart*

Siting Guidelines for Utility Application of Wind Turbines

AP-2795 Final Report (RP1520-1); $22.00

This report presents utility-oriented guidelines for identifying viable sites for wind turbines. Among the topics covered are predicting wind turbine performance at potential sites, analyzing wind turbine economics, estimating installation and maintenance costs, analyzing wind resource distribution over an area, and instrumentation for documenting wind behavior at potential sites. Extensive literature citations are included. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: F. R. Goodman, Jr.*

Wind Turbine Performance Assessment

AP-2796 Interim Report (RP1996-1); $14.50

This is the fifth in a series of technology status reports assessing the test data and experience of key federally and privately funded wind turbine research programs in the United States and Europe. It covers the period May–October 1981. The featured topic is foreign and privately funded domestic research. Updated test results for U.S. federally funded research programs are also given. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: F. R. Goodman, Jr.*

Distributed Solar Power Systems Economic Evaluation Program: User's Guide

AP-2804-CCM Computer Code Manual (RP1995-1); $11.50

This is the user's guide for the distributed solar power systems economic evaluation program (DSPSEVAL), a cash-flow analysis computer program that determines allowable prices for various solar electric power systems. Program calculations are based on electricity prices and the purchase criteria for residential payback, residential life-cycle costing, commercial and industrial payback and return on investment, leveraged investors (third party), and utilities. A hard-copy listing of the source code is provided. The contractor is Science Applications, Inc. *EPRI Project Manager: R. W. Taylor*

Environmental Characterization of the Texaco Coal Gasification Process at Ruhrkohle-Ruhrchemie

AP-2811 Final Report (RP1799-11); $17.50

This report presents the results of a limited environmental characterization of solid and liquid discharges from the Ruhrkohle-Ruhrchemie coal gasification pilot plant in Oberhausen-Holten, West Germany. Process data collected during a test run using Illinois No. 6 coal as feedstock are presented. Samples of effluent water, slag, raw coal, and settler fines are discussed, and effluent water treatability is evaluated. Calculations of material balances for major and trace elements around the plant are included. The contractor is Radian Corp. *EPRI Project Manager: John McDaniel*

Performance Comparison of 15- and 165-t/d Texaco Coal Gasifiers

AP-2814 Final Report (RP985-1); $8.50

To obtain gasifier scale-up data, results from steady-state tests at the Texaco Montebello 15-t/d coal gasification pilot plant are compared with results from Ruhrkohle-Ruhrchemie's 165-t/d demonstration plant. The report also presents qualitative results from parametric tests conducted to determine the influence of Selexol operating variables on H_2S, COS, and CO_2 removal from the syngas. The contractor is Texaco, Inc. *EPRI Project Manager: John McDaniel*

Electric Utility Solar Energy Activities: 1982 Survey Update

AP-2850-SR Special Report; $14.50

This report presents the results of the eighth annual EPRI survey on the scope of electric utility participation in U.S. solar energy projects. It contains brief descriptions of 128 new projects for 1982 and summarizes significant changes from 1981 in ongoing projects. Also included are an index of projects by category, a statistical summary, lists of participating utilities and information contacts, and a list of new project reports. *EPRI Project Manager: E. A. DeMeo*

COAL COMBUSTION SYSTEMS

Full-Scale Scrubber Characterization of Colstrip Unit 2

CS-2764 Final Report (RP1410-3); $37.00

Field testing and an engineering analysis were conducted to characterize the flue gas desulfurization (FGD) system at Montana Power Co.'s Colstrip Unit 2. Both regulated and unregulated emissions in the gas, liquid, and solid effluent streams of the scrubber system were measured. Mist eliminator performance was evaluated, and scrubber-generated particulate and scrubber sludge were analyzed. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Manager: R. G. Rhudy*

Characteristics of Waste Products From Dry Scrubbing Systems

CS-2766 Final Report (RP1870-2); $17.50

Disposal-related characteristics of dry-scrubbing FGD waste products were evaluated. Samples from different sources were examined to determine if they had similar disposal characteristics. This report details the findings of the tests performed—elemental analysis, X-ray diffraction and infrared compound identification, and an analysis of engineering properties. The contractor is Radian Corp. *EPRI Project Manager: R. G. Rhudy*

Lime FGD Systems Data Book, Second Edition

CS-2781 Final Report (RP982-23); $56.50

This report highlights the design and operating parameters of lime-based SO_2 scrubbing systems. It updates information on the technology status, expands the discussion of FGD systems currently in utility service, and presents a new discussion of spray absorber-dryer FGD systems. Detailed guidelines on design features, equipment specification, and selection criteria for lime scrubbers are presented. The relationship of process chemistry and component selection is discussed. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Manager: C. E. Dene*

Distribution and Analysis of High-Purity Magnesian Limestones in the United States
CS-2783 Final Report (RP982-21); $14.50

This report presents maps showing the distribution of major magnesium-containing limestones in the United States, as determined by a literature and operations data study. Wet chemical and X-ray analyses of 13 field samples are also summarized. It was found that commercially significant deposits of limestone containing at least 3% $MgCO_3$ and over 90% total carbonates ($CaCO_3$ and $MgCO_3$) are located primarily in the eastern United States and represent a minor portion of all limestone deposits. The contractor is Dravo Lime Co. *EPRI Project Manager: D. A. Stewart*

Slagging and Fouling by Coal-Oil Mixture in a Utility Boiler
CS-2787 Final Report (RP1455-1); $10.00

To further the understanding of ash deposit chemistry and behavior in a utility boiler firing a coal-oil mixture (COM), a field study of COM fouling and slagging was conducted. Special water-wall and superheater probes were fabricated for collecting ash and slag deposits from the boiler. Wet chemical analysis, fusibility measurements, and X-ray fluorescence and diffraction analyses were performed on the ash deposits collected. The contractors are Combustion Engineering, Inc., and New England Power Service Co. *EPRI Project Manager: R. K. Manfred*

FGD By-Product Disposal Manual, Third Edition
CS-2801 Final Report (RP1685-4); $80.00

A systematic, objective methodology is presented for evaluating candidate sludge disposal sites and methods. Background information and references on existing practices, federal regulatory constraints, and trends are given, as well as sludge disposal system costs. Updates are included on chemical and physical properties of FGD by-products; site selection methods, environmental monitoring, and site reclamation; dry scrubber wastes; and methods for estimating waste quantities and characteristics and leachate production rates. The contractor is Michael Baker, Jr., Inc. *EPRI Project Manager: D. M. Golden*

Electrostatic Precipitator Reference Manual
CS-2809 Final Report (RP1402-4); $34.00

This manual reviews the history of electrostatic precipitators (ESPs) and the theory on which they are based. The chemical and physical properties of fly ash are detailed, and practical guidelines for the selection of ESP design and size are presented. Special attention is given to operating and performance problem diagnostics, and trends in the design and application of ESPs are discussed. The contractor is C. A. Gallaer. *EPRI Project Manager: Walter Piulle*

NO_x Emissions From Pulverized-Coal Arch-Fired Boilers
CS-2813 Final Report (RP1339-1); $13.00

Arch-fired pulverized-coal furnaces are being evaluated as an alternative to conventional wall- and tangential-fired designs—specifically, in terms of their ability to meet federal New Source Performance Standards for NO_x emissions while retaining acceptable operating characteristics. This report presents the results of Phase 1 field testing conducted at eight arch-fired units of Wisconsin Electric Power Co. Phase 2 of the project will examine the engineering feasibility and costs of arch-fired designs. The contractor is KVB, Inc. *EPRI Project Manager: J. E. Cichanowicz*

Preliminary Evaluation of the Avco-Ebara FGT Process
CS-2817 Final Report (RP982-27); $13.00

The technical and economic feasibility of applying the Avco-Ebara flue gas treatment process to coal-fired utility steam generators is evaluated. The technical assessment addresses process chemistry, historical development, critical process parameters, areas requiring further development, safety and environmental concerns, and readiness for commercialization. A conceptual design for applying the process at a hypothetical generating station with two 500-MW units is described. The contractor is Bechtel Group, Inc. *EPRI Project Manager: T. M. Morasky*

Development of a Portable Field Monitor for PCBs
CS-2828 Final Report (RP1263-5); $10.00

This report summarizes efforts to develop a portable field instrument for measuring polychlorinated biphenyls (PCBs) in soil. In this work (which represents one facet of research on PCB disposal, spill conditions, and associated analytic techniques), portable monitors based on the principles of photoionization detection and infrared spectroscopy were adapted and evaluated for use under PCB spill conditions. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: R. Y. Komai*

Electrochemical Measurement of Corrosion Rates in Cathodically Protected Systems
CS-2858 Final Report (RP1689-7); $10.00

An electrochemical technique was evaluated as a nondestructive, in situ method of measuring corrosion rates for cathodically protected components in the tube–tubesheet–water box region of steam surface condensers. Measurements were made of harmonic current response to moderate sinusoidal voltage perturbation imposed on CuNi alloy and titanium specimens in artificial seawater. A mathematical procedure and a computer program developed in this study were used to calculate corrosion rates on the basis of the results. The contractor is SRI International. *EPRI Project Manager: B. C. Syrett*

ELECTRICAL SYSTEMS

Streamlined Procedure for Obtaining Regulatory Approval for New Transmission Lines
EL-1404 Final Report (TPS79-733); $11.50

This report outlines an efficient procedure for justifying transmission facility additions before regulatory commissions. The procedure, which is based on techniques, practices, and requirements identified in interviews with utility companies and regulatory commissions, addresses these issues: identification of line need, environmental analysis, transmission right-of-way selection, public relations, public review, and regulatory commission review process. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: N. J. Balu*

Long-Term, Mid-Term, and Short-Term Fuel Scheduling
EL-2630 Final Report (RP1048-6); Vol. 1, $29.50; Vol. 2, $17.50; Vol. 3, $22.00

This report details the development of digital computer programs to help utilities effectively use their fuel resources. Volume 1 contains a project overview and acts as a user's guide for two programs: an optimal fuel scheduling model for yearly fuel management and a special unit commitment program with fuel accounting logic for use when fuel supplies are limited. Volume 2 is the programmer's guide for these programs. Volume 3 presents an analysis of strategies for determining fuel prices for use in economic dispatch. The contractor is Boeing Computer Services, Inc. *EPRI Project Manager: C. J. Frank*

Distribution System Reliability Handbook
EL-2651 Final Report (RP1356-1); $14.50

This handbook presents two reliability assessment methods and the computer programs implementing the methods: a historical assessment model (HISRAM) and a predictive assessment model (PRAM). HISRAM is used to develop general outage reporting schemes that are suitable for a wide variety of distributing utilities, and PRAM examines the consequences of implementing or not implementing certain system reinforcement strategies. The contractor is Westinghouse Electric Corp. *EPRI Project Managers: R. Lambeth and W. E. Shula*

Transmission System Static VAR Control
EL-2754 Final Report (RP750-1); $20.50

To demonstrate the design methodology, practicality, and efficiency of static VAR control for power transmission systems, a static VAR generator has been designed, manufactured, and field-tested at Minnesota Power & Light Co.'s Shannon substation. This report presents analytic and design background material, as well as the empirical data generated in 12 months of field testing. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Gilbert Addis*

Detection of Arcing Faults on Distribution Feeders
EL-2757 Final Report (RP1285-3); $14.50

A study was conducted to design and test a microcomputer-based prototype detector for arcing, high-impedance faults. This report covers fault detection theory and the characteristics of high-impedance faults; system design and development, including hardware and operational considerations; and the field-test instrumentation, measurements, and data analysis. The contractor is the Texas A&M Research Foundation. *EPRI Project Manager: H. J. Songster*

Fungal Associates, Detection, and Fumigant Control of Decay in Treated Southern Pine Poles
EL-2768 Final Report (RP1471-); $13.00

This report describes efforts to demonstrate the effective arrest and control of fungi growth in southern pine poles by the application of the fumigants Vapam and chloropicrin. Several methods for detecting decay in poles were also evaluated. Cultural and dissection studies were conducted to determine decay patterns and associated fungi; seven patterns are described. The contractor is the State University of New York. *EPRI Project Manager: R. S. Tackaberry*

Effects of Reduced Fault Duration Upon Power System Components
EL-2772 Final Report (RP1498-1); $14.50

In work aimed at extending the fault current capacity of transmission substations, the feasibility of a greatly simplified alternative to the fault current limiter was investigated. Two schemes based on the concept were assessed: one involving a high-speed breaker and a reactor (equipment with high reliability) and another involving only a high-speed breaker. Utility industry needs and fault current characteristics are discussed, as well as a specific 69-kV application of the concept. The contractor is Stanford University. *EPRI Project Manager: N. G. Hingorani*

User's Guide to Producing Coherency-Based Equivalents for Transient Stability Studies
EL-2778-CCM Computer Code Manual (RP763); $23.50

This report is a user's guide for DYNEQ3, a computer program that reduces a large-scale system model to a small dynamic equivalent model for use in transient stability studies. A sample run is included. The simulation test results indicate that a 40% reduction in computation time can be realized by employing this system for transient stability simulations. The contractor is Consumers Power Co. *EPRI Project Manager: J. V. Mitsche*

Explosion-Resistant Bushings for Gas-Insulated Equipment
EL-2788 Final Report (RP1423-1); $10.00

This report outlines work to develop explosion-resistant bushings for use in gas-insulated equipment—specifically, capacitive-graded, oil-less bushings that are smaller than bulk gas insulation bushings and lower in cost. The project assessed the feasibility of extending, to the 500-kV voltage class, manufacturing techniques used for paper-resin capacitor bushings. The contractor is Lapp Division, Interpace Corp. *EPRI Project Manager: V. H. Tahiliani*

Bipolar HVDC Transmission System Study Between ±600 kV and ±1200 kV: Corona Studies, Phase 2
EL-2794 Final Report (RP430-2); $20.50

This report documents a study of the corona performance characteristics of a 6 × 4.06 cm conductor bundle tested under all possible weather conditions and at voltages ranging from ±750 to ±1050 kV. Radio interference, audible noise, and corona loss performance were evaluated, and the influence of line voltage on these parameters was studied. Data were collected on the lateral profiles of radio interference, audible noise, ion current density, and electric field at ground level. Electric field and ion induction effects on people and objects were also investigated. The contractor is Institut de Recherche de l'Hydro-Québec. *EPRI Project Manager: J. H. Dunlap*

Probabilistic Approach to Stability Analysis
EL-2797 Final Report (RP1764-4), Vol. 1; $35.50

A project was undertaken to develop a probabilistic approach to power system stability. This volume describes a probabilistic disturbance model and a model of the protective system. It discusses the type, location, and sequence of system disturbances; statistical distribution of disturbances and of stability; and protective system configurations. Methods whereby the probability of stability can be computed, either by Monte Carlo simulation or by direct analytic transformation, are presented. The contractor is Arizona State University. *EPRI Project Manager: N. J. Balu*

ENERGY ANALYSIS AND ENVIRONMENT

Review of Energy Productivity Center's Least-Cost Energy Strategy Study
EA-2753 Interim Report (RP1484); $17.50

This report presents a thorough review of a study by the Mellon Institute's Energy Productivity Center, *The Least-Cost Energy Strategy: Minimizing Consumer Costs Through Consumption*. The study's methodology, data base, and results are assessed. Where possible, the report presents conclusions about the usefulness of the study for policy analyses, identifies policy parameters, and notes the sensitivity of the results to changes in input assumptions. The contractor is the Massachusetts Institute of Technology. *EPRI Project Manager: Richard Richels*

Integrated Lake-Watershed Acidification Study: Annual Review Conference
EA-2827 Proceedings (RP1109-5); $26.50

Progress of the integrated lake-watershed acidification study (ILWAS) through the fall of 1980 is summarized. This report contains 14 papers presented at the 1980 annual review, including preliminary analyses of deposition, through-fall, hydrology, vegetation, soils, geology, microbial activity, lake water chemistry, lake sediments, and historical acidity. The contractor is Tetra Tech, Inc. *EPRI Project Manager: R. A. Goldstein*

Energy Use and Customer Welfare Effects of Residential TOU Rates
EA-2832 Final Report (TPS78-777); $10.00

This report presents an economic analysis of residential customer response to time-of-use (TOU) pricing of electricity. The analysis is based on data from a Wisconsin TOU project for July 1977. Both customer response and customer welfare estimates are generated endogenously within a consistent framework. Estimates of the elasticities of substitution are provided. The contractor is Richard W. Parks. *EPRI Project Manager: Ahmad Faruqui*

ENERGY MANAGEMENT AND UTILIZATION

Feasibility Assessment of Customer Battery Energy Storage Applications
EM-2769 Interim Report (RP1275-12); $13.00

This report examines important technical and economic factors regarding customer-owned battery energy storage installations. Battery storage system designs and costs are described and quantified, and current rates and customer load profiles are used in developing an economic analysis for a range of generic applications. The sensitivity of the results to various parameters is discussed. The contractor is Bechtel Group, Inc. *EPRI Project Manager: D. L. Douglas*

Plasma Processing for Materials Production
EM-2771 Final Report (RP1275-9); $11.50

This report surveys thermal plasma processing with particular reference to the potential U.S. market for increased industrial electrification. Only those plasma processes that have been demonstrated commercially or at the pilot stage or that have received extensive laboratory investigation are considered. Technical and economic comparisons of these processes with conventional processes are presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: I. L. Harry*

DEUS Computer Evaluation Model
EM-2776 Final Report (RP1276-4); Vol. 1, $20.50; Vol. 2, $16.00

This report presents DEUS, a computer simulation model of dual energy use systems. The model is designed for the evaluation of cogeneration systems and is a useful tool for utilities as well as cogenerators. Volume 1 describes the program methodology and its data base; Volume 2 is a user's manual. The contractor is General Electric Co. *EPRI Project Manager: S. D. Hu*

CAES: Commercialization Potential and EPRI Roles
EM-2780 Final Report (RP1199-15); $16.00

This report presents an assessment of potential EPRI roles in facilitating the commercial acceptance of compressed-air energy storage (CAES) systems. Detailed analyses of the market potential of utility storage technologies are provided, and interviews with representatives of key participants in the CAES market are summarized. A decision analysis synthesizing much of the information about market and technology status is included. The contractor is Decision Focus Inc. *EPRI Project Manager: R. B. Schainker*

NUCLEAR POWER

RETRAN-02: Applications
NP-1850-CCM Computer Code Manual (RP889), Vol. 4; $31.00

This volume describes the verification effort associated with the development of RETRAN-02, a code for the transient thermal-hydraulic analysis of complex fluid flow systems. Results of analyses used to evaluate and qualify the code for various applications are presented. The contractor is Energy Incorporated. *EPRI Project Manager: L. J. Agee*

PWR Safety and Relief Valve Test Program: Valve Selection/Justification
NP-2292 Final Report (RPV102); $25.00

NUREG 0578 required that full-scale testing be performed on pressurizer safety valves and relief valves representative of those in use or planned for use in PWR plants. Nine safety valves [later reduced to seven] and ten relief valves were selected as a fully representative test set. Justification that the selection represented all PWR plant valves was provided by each valve manufacturer. This report documents the valve selection and justification effort. The contractors are MPR Associates, Inc.; participating PWR safety and relief valve manufacturers; and the EPRI PWR safety and relief valve test program staff. *EPRI Project Manager: T. E. Auble*

Valve Inlet Fluid Conditions for Pressurizer Safety and Relief Valves in Westinghouse-Designed Plants

NP-2296 Final Report (RPV102-19); $10.00

The expected range of inlet fluid conditions is presented for pressurizer safety and relief valves used in Westinghouse-designed PWR units. FSAR (final safety and analysis report), extended high-pressure liquid injection, and cold overpressurization events were considered. The Westinghouse PWR units were grouped by design and layout, a reference plant was chosen for each group, and valve inlet fluid conditions were determined for each reference plant. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: John Hosler*

BWR FIST Program Test Plan

NP-2313 Interim Report (RP495-1); $8.50

This report presents a test plan for the BWR full integral simulation test (FIST) program, which will investigate BWR thermal-hydraulic response under loss-of-coolant accident and operational transient conditions in a scaled BWR test apparatus. The selection of test parameters, the defining of individual tests, and the measurement and data utilization plans are discussed. The contractor is General Electric Co. *EPRI Project Manager: S. P. Kalra*

Valve Inlet Fluid Conditions for Pressurizer Safety and Relief Valves in Combustion Engineering–Designed Plants

NP-2318 Final Report (RPV102-20); $11.50

Documented information was assembled for Combustion Engineering–designed PWR units concerning pressurizer safety and relief valve inlet fluid conditions during actuation as calculated by conventional licensing analyses. Available FSAR-reload analyses and certain low-temperature overpressurization analyses were reviewed, and the extended high-pressure liquid injection event was also considered. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: John Hosler*

Valve Inlet Fluid Conditions for Pressurizer Safety and Relief Valves for B&W 177-FA and 205-FA Plants

NP-2352 Final Report (RPV102-17); $14.50

Overpressurization transients for Babcock & Wilcox–designed 177- and 205-FA units were reviewed to determine the range of fluid conditions expected at the inlet of pressurizer safety and relief valves. FSAR, extended high-pressure injection, and cold overpressurization events were considered. The results provide input to PWR utilities in justifying that the fluid conditions under which their valve designs were tested in the EPRI test program are representative of those expected in their units. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: John Hosler*

EPRI PWR Safety and Relief Valve Test Program: Test Condition Justification

NP-2460-SR Special Report; $14.50

In response to requirements in NUREG 0737, several safety and relief valve designs were tested by EPRI under PWR utility sponsorship. This report justifies that the inlet fluid conditions under which these valve designs were tested are representative of those expected in participating domestic PWR units during FSAR, extended high-pressure injection, and cold overpressurization events. *EPRI Project Manager: John Hosler*

Application of RELAP5/MOD1 for Calculating Safety and Relief Valve Discharge Piping Hydrodynamic Loads

NP-2479 Final Report (RPV102-28); $26.50

Experimental data from five safety valve tests are compared with RELAP5/MOD1 calculations to evaluate the code's capability to determine fluid-induced transient loads on downstream piping. The test conditions included steam, saturated water, and loop seal discharge conditions. The contractor is Intermountain Technologies, Inc. *EPRI Project Manager: A. J. Wheeler*

Parametric Study of CHF Data

NP-2609 Final Report (RP813), Vol. 2; $13.00

This volume describes the development of a generalized subchannel critical heat flux (CHF) correlation for PWR and BWR fuel assemblies. The effects of nonuniform axial heat flux, cold walls, and grid spacers are discussed, and the correlation's performance is compared with a wide range of data. The contractor is Columbia University. *EPRI Project Manager: Mati Merilo*

EPRI PWR Safety and Relief Valve Test Program: Test Report

NP-2628-SR Special Report; $22.00

This report describes the testing of seven safety valves and ten relief valves that are representative of those in use or planned for use in participating domestic PWRs. The as-tested test matrices, valve performance data, and principal observations are presented in such a way that participating utilities may use the results to develop their response to NRC recommendations documented in NUREG 0578 and clarified in NUREG 0737. *EPRI Project Managers: T. E. Auble and John Hosler*

Diversion-Resistant Nuclear Fuels Processing: Progress Report

NP-2633 Interim Report (RP1578-2); $26.50

This progress report describes the 1980–1981 activities and findings of the diversion-resistant nuclear fuels processing project, which is being conducted to identify and evaluate specific design features that can be incorporated into reprocessing and fuel fabrication plants to improve the plants' diversion resistance. The study's six parts are described, and preliminary conclusions are addressed. The contractor is Exxon Nuclear Co., Inc. *EPRI Project Manager: R. W. Lambert*

Evaluation of Stainless Steel Cladding for Use in Current-Design LWRs

NP-2642 Final Report (TPS79-773); $20.50

This report describes a project to evaluate the potential benefits and disadvantages of substituting stainless steel–clad fuel for currently used Zircaloy-clad fuel. The design of stainless steel–clad LWR fuel is discussed, as well as its performance at steady-state, transient, and accident conditions. The technology and fuel-cycle costs of stainless steel–clad and Zircaloy-clad fuels are compared for a large PWR. The contractor is S. M. Stoller Corp. *EPRI Project Manager: David Franklin*

Metal Cation Inhibitors for Controlling Denting Corrosion in Steam Generators

NP-2655 Final Report (RPS147-1); $14.50

This report discusses various theoretical mechanisms that explain how metal cations inhibit or prevent the corrosion of carbon steel. Laboratory corrosion and electrochemical testing methods and evaluation techniques are also described, and the results from such testing are presented. The contractor is Lehigh University. *EPRI Project Manager: C. S. Welty, Jr.*

Evaluation and Categorization of Secondary-System Layup and Cleanup Practices for PWR Plants

NP-2656 Topical Report (RPS113-1); $22.00

To determine ways to minimize corrosion-product transport to the secondary side of PWR steam generators, layup and post-shutdown cleanup practices now in use or proposed by utilities with operating PWR plants were examined. The results show that about 30% of the plants attempt routine layup of secondary systems during plant outages and about 60% attempt system cleanup before and during startup. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Reliability of Steam Turbine Rotors: Lifetime Prediction Analysis System

NP-2661 Final Report (RP502-1); $10.00

This report describes the SAFER computer code, a rotor lifetime prediction method that can provide a mechanism for systematic handling of the large volume of data generated in a turbine rotor inspection. Work on the code is part of the development of the steam turbine rotor analysis program (STRAP). SAFER is compared with STRAP, and its capabilities are detailed. The contractor is Southwest Research Institute. *EPRI Project Managers: F. E. Gelhaus and M. J. Kolar*

Low-Level Waste Disposal Site Performance Assessment With the RQ/PQ Methodology

NP-2665 Final Report (RP2063-1); $13.00

This report presents a methodology for analyzing nuclide migration for the multiple pathways that must be considered in calculating the safety of a shallow land burial site for low-level waste. Designed to assist in site screening and selection, the RQ/PQ (retention quotient/performance quotient) methodology permits the rapid evaluation of different waste forms, waste burial depth, cover thickness, geohydrology, and other relevant siting parameters. The contractor is Rogers and Associates Engineering Corp. *EPRI Project Manager: R. F. Williams*

Feasibility of and Methodology for Thermal Annealing an Embrittled Reactor Vessel

NP-2712 Final Report (RP1021-1); Vol. 1, $10.00; Vol. 2, $37.00

Results are presented from a five-year program to determine the feasibility of thermal annealing an embrittled reactor vessel and to develop an effective methodology. Volume 1 is an executive summary. Volume 2 contains a detailed description of the work, including a conceptual design for thermal annealing equipment and an assessment of design limitations and system restrictions. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: T. U. Marston*

BWR Neutron Absorption Standards

NP-2731 Final Report (RP1628-5); $14.50

This report documents work to evaluate the capabilities of a neutron detector developed earlier (NP-2730) for the nondestructive inspection of BWR control blades. The fabrication and characterization of simulated neutron absorber standards (type-304 stainless steel tubing with various loadings of boron carbide powder) are described, as well as the inspection of these standards by the neutron detector. The contractor is Science Applications, Inc. *EPRI Project Manager: Howard Ocken*

Expected Performance of Spent LWR Fuel Under Dry Storage Conditions

NP-2735 Final Report (RP2062-1); $8.50

This report presents a review of available data for evaluating LWR spent-fuel performance under dry storage conditions. A number of spent-fuel degradation mechanisms applicable to the dry storage environment are discussed, and conclusions are presented. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: R. W. Lambert*

Nondestructive Testing of Large Steam Turbine Rotors

NP-2736 Final Report (RP502-2); $20.50

This report describes efforts connected with the development of a steam turbine generator rotor lifetime prediction system that uses field ultrasonic inspection results as input. Work covered includes the evaluation of alternative near-bore inspection techniques; the development of the bore ultrasonic characterization system (BUCS); the inspection of three retired rotors; and the destructive analysis of the three rotors to compare ultrasonic results with actual flaw location and dimensions. The contractors are Battelle, Columbus Laboratories and Southwest Research Institute. *EPRI Project Managers: F. E. Gelhaus and M. J. Kolar*

Metallurgical Evaluation of a Failed LP Turbine Disk

NP-2738 Final Report (RP1398-6); $11.50

This report describes a metallurgical evaluation of a burst disk from the low-power turbine at the Yankee Rowe nuclear generating station. It discusses the general features of the main fracture and presents the results of a magnetic particle inspection, a metallographic and fractographic evaluation, and a surface deposit analysis. Composition, microstructure, and mechanical properties are also addressed. The contractor is Southwest Research Institute. *EPRI Project Manager: M. J. Kolar*

Scale-Model Turbine Missile Casing Impact Tests

NP-2742 Final Report (RP399-2); $13.00

This report describes three 1/5-scale-model turbine missile impact experiments performed to provide benchmark data for assessing turbine missile effects in nuclear plant design. The development of an explosive launcher to accelerate the turbine missile models to the desired impact velocities is described. A comparison of the test results with those from full-scale experiments demonstrates scalability. The contractor is SRI International. *EPRI Project Manager: G. E. Sliter*

ERUDITE User's Guide

NP-2755-CCM Computer Code Manual (RP1321-3); $20.50

This document is a revision of the user's guide for the ERUDITE transient fuel behavior data base. (The guide was first published in March 1981 as NP-1766-CCM.) Data from 53 test rod records are described. The contents of ERUDITE are listed in detail, and the method for accessing the data is given in practical form. The guide explains necessary portions of DATATRAN, a noninteractive system that allows ready access to, and easy manipulation of, the data in the base. The contractor is Intermountain Technologies, Inc. *EPRI Project Manager: A. G. Adamantiades*

Radiation-Field Control by Single Steam Generator Cooldowns

NP-2756 Interim Report (RP825-1); $14.50

Data on steam generator radiation levels were compiled for several power reactor cooldowns that used a single steam generator while isolating the second steam generator. The cooldown procedure is described, and one cooldown at Oconee-2 is examined in detail, including primary- and secondary-system performance. Steam generator secondary-side heating as a means of crud reduction is also addressed. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: R. A. Shaw*

Decision Analysis Applied to a Utility's Decisions Resulting From IGSCC

NP-2758 Final Report (RP1542-2); $11.50

This report details the application of decision analysis to the issue of intergranular stress corrosion cracking (IGSCC) in BWR pipe welds. One utility's financial decision-making constraints and plant-specific input were used in the analysis to examine three major alternatives: application of induction heating stress improvement, replacement of piping with an improved material, and repair of pipe cracks as required by failure observation. The contractor is Strategic Decisions Group. *EPRI Project Manager: S. W. Tagart, Jr.*

Reconstituted Charpy Impact Specimens

NP-2759 Final Report (RP2055-3); $10.00

This report describes the arc stud welding process for producing new, full-size Charpy V-notch impact specimens from halves of previously tested Charpy specimens. Various techniques are reviewed, specimen preparation is discussed, and the arc stud welding gun equipment is described. The contractors are Fracture Control Corp. and Battelle, Columbus Laboratories. *EPRI Project Manager: T. U. Marston*

High-Temperature Elastic-Plastic and Creep Properties for SA533 and SA508 Materials

NP-2763 Topical Report (RP2055-8, TSA81-485); $10.00

This report describes the results of a project to determine the creep and elastic-plastic properties of two reactor vessel materials (SA533 Grade B Class I and SA508 Class II steels) in the temperature range of 70–1200°F. The experimental data are analyzed and reduced to constitutive equations. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: L. E. Anderson and T. U. Marston*

Measurement and THEDA Prediction of Thermal, Velocity, and Pressure Fields in an OTSG Heated-Air Model

NP-2765 Final Report (RPS179-1); $41.50

A full-scale, partial-section once-through steam generator (OTSG) model was modified and used for tests with heated air as the working fluid. Test data on velocity, temperature, and pressure distribution are assessed, and the feasibility of lane blockers to divert flow from the lane to the tube bundle in order to evaporate water droplets and prevent corrosion is discussed. Data are compared with predictions by THEDA-2A, an air-property version of the three-dimensional thermal-hydraulic code THEDA-2. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. L. Williams*

Evaluation of Thermal Mixing Data From a Model Cold Leg and Downcomer

NP-2773 Interim Report (RP2122-3); $17.50

This report describes the evaluation of data on fluid and thermal mixing obtained from tests in a 1/5-scale model of a PWR cold leg and downcomer (NP-2312). Analyses are included on temperature distributions, velocities in the buoyant plume, flow regimes, and the rate of temperature drop. The data—relevant to the mixing phenomenon following high-pressure injection of coolant water in a PWR loop—are reduced, correlated, and compared with theoretically derived values and scaling approaches. The contractor is Creare, Inc. *EPRI Project Manager: K. H. Sun*

Steam Generator Probe Positioning Device

NP-2774 Final Report (RPS125-3); $8.50

This report presents a study of the feasibility of a device that would eliminate the need for manned entry into a steam generator channel head to emplace positioning devices for tubing inspection probes. This study is part of a series of projects to improve steam generator inspection methods. The proposed device would offer reduced radiation exposure, shorter inspection time, and greater versatility and speed and would require less operator skill and training. The contractor is NUS Corp. *EPRI Project Manager: S. T. Oldberg*

Corrosion Fatigue Characterization of Reactor Pressure Vessel Steels

NP-2775 Interim Report (RP1325-1); $20.50

This report documents Phase 1 of a project to provide a basis for developing an improved crack growth prediction method. It describes a four-autoclave test facility in which computer-controlled fatigue crack growth experiments can be performed on compact fracture specimens in well-controlled, high-temperature environments. Results from initial tests are presented. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: R. L. Jones*

Comparison of Decontamination Techniques for Reactor Coolant System Applications

NP-2777 Final Report (RP2012-2); $10.00

This report evaluates the suitability of various nonchemical decontamination methods for use in

PWR primary cooling systems, specifically the system at Three Mile Island Unit 2. A systematic, quantitative comparison is made of techniques that were identified in NP-2690. Different categories of components are defined, and a separate comparison is included for each. The contractor is Quadrex Corp. *EPRI Project Manager: L. E. Anderson*

Evaluation and Prediction of Neutron Embrittlement in Reactor Pressure Vessel Materials

NP-2782 Final Report (RP886-2); $17.50

The effects of fast neutron irradiation on the mechanical properties of eight nuclear reactor vessel materials, including submerged arc weldments, are evaluated. Correlations between impact and fracture toughness parameters are developed from the experimental results. The observed shifts in transition temperature and the drop in upper-shelf energy are compared with predictions developed from the Regulatory Guide 1.99.1 trend curves. The contractor is the Naval Research Laboratory. *EPRI Project Manager: T. U. Marston*

Comparison of Selected Risk Contributions of an LMFBR and an LWR

NP-2784 Final Report (RP2031-1); $23.50

The unavailability of the reactor shutdown and emergency decay heat removal systems of a prototype 1000-MW (e) pool breeder reactor was analyzed for two accident initiators—loss of offsite power and loss of main feedwater. The fault tree–event tree methodology was used. On the basis of the computed results, the estimated core degradation probability for an LMFBR is significantly lower than the core melt probability for an LWR. The contractor is Science Applications, Inc. *EPRI Project Manager: A. G. Adamantiades*

Effects of Residual Stress on the UT Detectability of Surface Cracks in Feedwater Nozzles

NP-2785 Final Report (RP1543-2); $10.00

This report documents a study of how service-induced residual stresses due to high-amplitude thermal loading affect the ultrasonic testing (UT) detectability of surface cracks in BWR feedwater nozzles. Two-dimensional transient temperature analyses, coupled in time with elastic-plastic analyses of a reference BWR nozzle design, were performed over a wide range of loading and geometric variables. The results show that crack closure behavior is governed by such variables as crack length, service history, and unloading sequence. The contractor is Anatech International Corp. *EPRI Project Manager: R. E. Nickell*

Waterside Corrosion of Zircaloy Fuel Rods

NP-2789 Final Report (RP1250-1); $17.50

This two-part report presents the results of a comprehensive investigation of Zircaloy cladding corrosion in PWRs. Part 1 discusses oxide thickness measurements and the effect of various design and reactor operating parameters on Zircaloy corrosion. Oxide film characterization data, thermal-hydraulic analyses, and statistical analyses of the data are also presented. Part 2, on microfiche, provides the oxide thickness data obtained from individual fuel rods. The contractors are Kraftwerk Union, Ag, and Combustion Engineering, Inc. *EPRI Project Manager: Howard Ocken*

OTSG Tube Failures: Upper Tubesheet Corrosion Tests

NP-2790 Final Report (RPS165-1); $13.00

Tests were conducted on a simulated upper tubesheet of a once-through steam generator (OTSG) as a means of identifying and understanding the role of chemical contaminants in corrosion damage in the Oconee steam generator. Acidic and alkaline solutions were applied to tubes to simulate conditions that might be responsible for field tube failures, and surface deposit and metallurgical analyses were conducted on the test specimens. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. L. Williams*

Proceedings: Support Structure Corrosion in Steam Generators

NP-2791 Proceedings (WS82-115); $32.50

This report documents an EPRI workshop held in Boston in May 1982 to discuss support structure corrosion in steam generators. Designed to present information on available materials and designs for support structures and to determine utility needs, the workshop covered crevice corrosion rates for alloy steels and carbon steel, results from examinations of support plate segments removed from steam generators, and models for corrosion and salt hideout in crevices. *EPRI Project Manager: C. E. Shoemaker*

Development of a Fiber Optic Doppler Anemometer for Bubbly Two-Phase Flows

NP-2802 Final Report (RP1159-3); $13.00

This report describes the development of state-of-the-art instrumentation for use in two-phase thermal-hydraulic analysis. It details two types of fiber optic Doppler anemometers that are capable of measuring both vapor and liquid velocities and void fraction on a local basis with high resolution. Results of tests conducted with these instruments are presented. The contractor is Lehigh University. *EPRI Project Manager: G. S. Lellouche*

Water Entrainment in Intercompartmental Flow

NP-2803 Final Report (RP275-1-3); $13 00

This report describes an experimental program conducted to examine the phenomena associated with the process of entrainment. The results of air-water and steam-water entrainment tests are presented, and the physical process involved is discussed. The development of air-water and steam-water lumped entrainment models is also addressed. The contractor is Drexel University. *EPRI Project Manager: G. S. Lellouche*

Transient Library for Validating Nuclear Plant SPDS

NSAC-38; $13.00

This report describes a new magnetic tape–based library of nuclear power plant simulator transients. The library will enable a utility to drive a safety parameter display system (SPDS) with actual transient data for the purposes of system checkout, testing, training, and validation (without the expense of moving the system to a simulator). The initial library contains one set each of BWR and PWR transients. The contractor is Nuclear Software Services, Inc. *EPRI Project Manager: D. G. Cain*

PLANNING AND EVALUATION

1983–1987 Research and Development Program Plan

P-2799-SR Special Report; $10.00

This report describes the R&D programs of EPRI's six technical divisions for the period 1983–1987. The major specific objectives, the importance to the electric utility industry and its customers, motivating issues, technical impediments, anticipated key events, and planned expenditures over the next five years are presented for each program. *EPRI Contact: Myra Fraser*

R&D Benefits Assessment: A Regional Approach

P-2851-SR Special Report; $13.00

This report discusses the development of a methodology based on the use of regional generation systems to assess the benefits of EPRI R&D programs to the utility industry. The EPRI regional systems approach, developed to help quantify potential capital and operating cost savings resulting from the introduction of new and improved technologies, is described in full, and four case study applications are analyzed. *EPRI Project Manager: J. J. Mulvaney*

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