Changing Currents in Hydro

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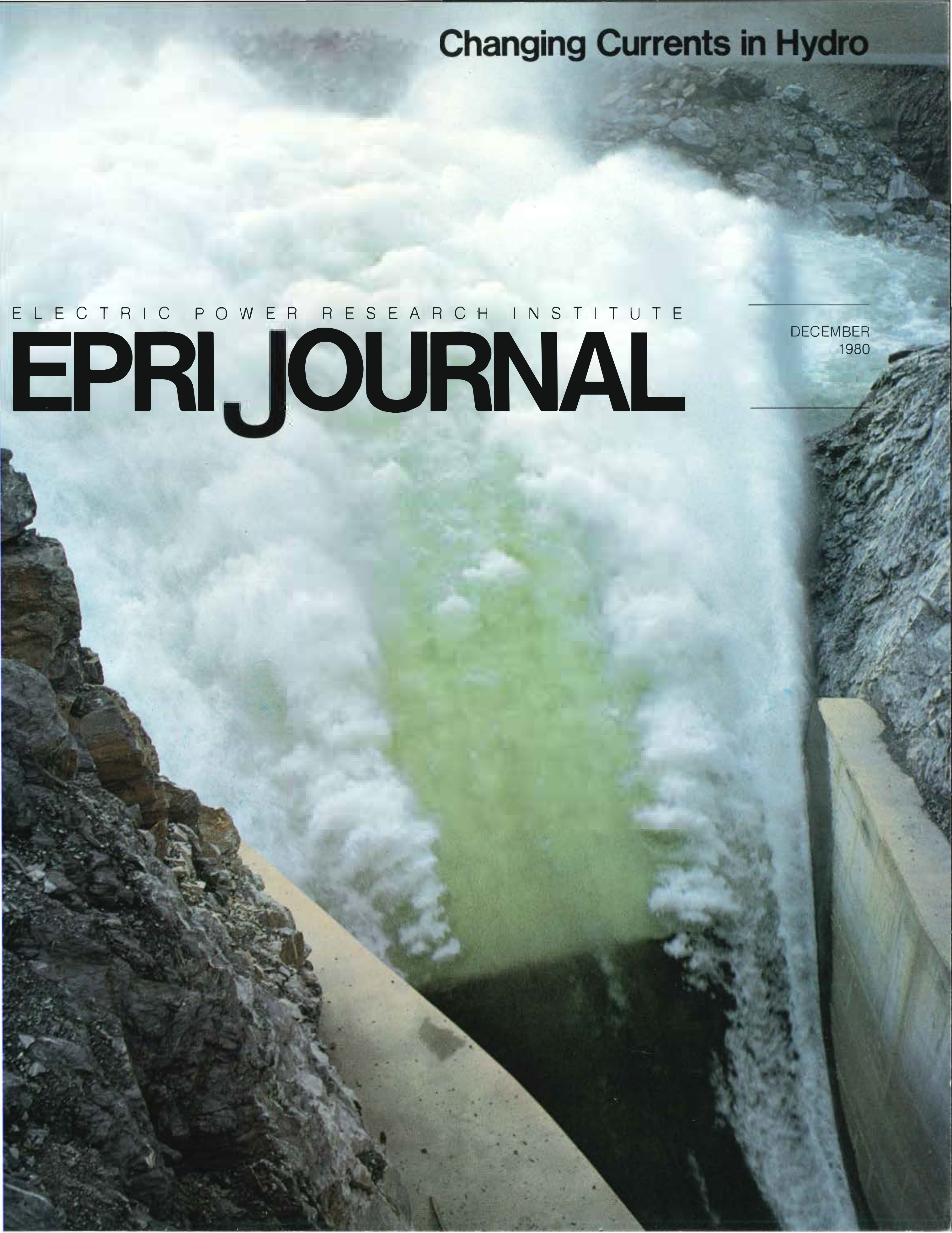

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Cover: Utilities are increasingly interested in hydro as the price of electricity from other sources rises. This power storage dam on a tributary of the Columbia River is owned by British Columbia Hydro and Power Authority. *Photo courtesy Bonneville Power Administration.*

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New Perspectives on Hydro

Hydroelectric power generates about 12% of the electric energy in the United States today; it is the nation's dominant renewable source of energy. Hydro's future potential may seem limited; after all, the obvious hydro sites are already occupied by power plants. But as the cost of electricity from other sources soars, utilities are paying more and more attention to increasing output from existing hydro plants and building new plants at sites that once seemed uneconomical. This issue's cover story discusses the utility industry's renewed interest in hydro and identifies opportunities for further development of our hydroelectric resources.

The potential for utilities to save fossil fuel through new or expanded hydro facilities is considerable: the addition of just 10 GW of hydro capacity (one-fifth of the estimated expansion potential of present-day generating sites) could save about 50 million barrels of oil a year, and the annual dollar savings for that amount of fuel would be over $1.5 billion. Hydro offers savings also in operation and maintenance costs—the robust structures and relatively simple equipment are long-lived when properly maintained, and they are less complex than other power plants. Once installed, hydro plants generate electricity at costs that are virtually unaffected by inflation.

The expansion of existing hydro sites should be relatively straightforward. In some cases, however, the development of new sites will face a number of physical and economical obstacles (in addition to the institutional and environmental obstacles that can affect both new and existing hydro sites), but many of the development hurdles can be surmounted by well-planned research.

EPRI's Energy Management and Utilization Division is now organizing such a research effort. As part of this endeavor we have been assessing hydro's potential for the utility industry, identifying research needs, and assigning priorities to those needs. We believe that the state of the art of hydroelectric technology can still be advanced significantly; promising opportunities to do so exist in the development of high-head pump-turbines and of larger unit sizes with the ability to govern power output. The performance, reliability, and availability of existing and new generating units can be improved. Capital, operation, and maintenance costs at hydro facilities can be reduced. Further, the safety of existing and new dams should be enhanced, and public and environmental acceptance of hydro facilities should be strengthened. Modern technological and management approaches will greatly assist this new development push; so will the enthusiasm of hydroelectric equipment suppliers, who have already begun to respond to renewed sales opportunities in hydro with updated technology.

Hydroelectric generation is an increasingly important source of electric energy. Its revitalized development is a response to the nation's need for renewable energy sources that can compete technologically, economically, and environmentally with existing fossil fuels. With effective leadership from the utility industry, hydro's potential can be achieved. The need is obvious, the sites are there, and assisted by ongoing R&D, the economics will become increasingly attractive.

Thomas R. Schneider

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Assistant Director
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Authors and Articles

Low-head hydroelectric plants came first, bringing electricity to small service areas along steadily flowing rivers throughout the eastern United States in the 1880s and 1890s. By the 1930s high-head dams made river regulation possible, and hydro became a major baseload power source, even in arid western watersheds. The 1940s and 1950s saw multipurpose projects deliver electricity, as well as irrigation water and flood control benefits, to entire regions. These developments led to the current inventory of some 1500 hydro power plants nationwide, totaling 64 GW of capacity and producing about one-eighth of our annual electricity.

As a fraction of U.S. generation, hydro may have seen its heyday, but **Lifting Hydro's Potential** (page 6) reviews how opportunity, need, and new technology, substantiated by recent federal and EPRI assessments, may spur utilities to double today's capacity in the next several decades. And once again, low-head hydro represents much of the potential, according to Nadine Lihach, *Journal* feature writer, and Antonio Ferreira, manager of hydroelectric and related energy storage projects for EPRI's Energy Management and Utilization Division.

Ferreira has been on loan to EPRI from Northeast Utilities Service Co. since 1977. Formerly he was the utility's civil engineering chief of generation and earlier its project manager for the pioneering Northfield Mountain underground pumped storage project, which began operation in 1973. Before 1966, Ferreira was with Western Massachusetts Electric Co. for 15 years, becoming the company's top hydraulic engineer.

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First it was exhaust mufflers to reduce noise. Early automobile buffs hated them because they created backpressure that cut the modest horsepower then available. More recently, catalytic exhaust gas converters have been the energy parasites, but Detroit is now reckoning with emission controls at the outset of its automotive designs. William Nesbit, author of **Streamlining the Environmental Control Package** (page 14), traces a similar evolution of attitudes and practices in the design of coal-fired power plant emission controls. Today's incentive is higher plant efficiency and reliability and, consequently, a potential lid on the cost of systems that now represent 40% of a coal-fired plant investment. The "Detroit" of this article is EPRI's Coal Combustion Systems Division, where emission control techniques are being combined in preliminary studies and in pilot plant tests to establish integrated systems that will optimize overall plant performance.

Dan Giovanni, who manages the Air Quality Control Program and leads the research project on integrated emissions control, furnished background for the article. For most of his career, Giovanni has specialized in power plant emissions reduction and performance improvement. He worked with KVB, Inc., as a consultant to utilities and power equipment manufacturers; later he joined Kaiser Aluminum & Chemical Corp. to direct research in the energy efficiency of aluminum fabricating processes. He has been with EPRI since December 1977. Giovanni holds a BS and an MS in mechanical engineering from the University of California at Berkeley.

■

There's no such thing as just plain water in a thermal power plant. Chemistry is the key issue for boiler feedwater; it must be free of corrosive compounds. Temperature is the key issue for cooling water; it must extract heat efficiently from condensers, but its flow patterns and temperature changes must not upset aquatic life in a lake or river.

Protecting Fish From Cooling-System Effects (page 20) reviews research to better define and control the characteristics of cooling water that impose stress on aquatic systems, mainly fish populations. The author is Jenny Hopkinson, *Journal* feature writer; her principal resource is Ishwar Murarka, project manager in the Environmental Assessment Department of EPRI's Energy Analysis and Environment Division.

Murarka began his EPRI work in ecological effects in October 1979. For five years before that he was a scientist in environmental impact studies for Argonne National Laboratory, where he also developed statistical sampling methods and mathematical models to assess the impingement of fish at cooling-water intakes. During the same period he was an adjunct assistant professor at Northern Illinois University, continuing the teaching begun when he was a graduate student and research assistant. Murarka has a BS in geography from the University of Calcutta, an MS and a PhD in soil science from Oregon State University, and an MBA from the University of Chicago.

■

Grinding out R&D on energy generation technology yields increments of performance efficiency, known as technical energy conservation. Grinding out other R&D on new fuel resources and their conversion yields other increments of energy supply. But these individually valid contributions do not automatically change the overall use pattern.

Arthur Bueche of General Electric Co. surveyed that overall pattern when he spoke before EPRI's Advisory Council at its annual seminar last August. **Energy Conservation, Efficiency, and Substitution** (page 24) is adapted from his speech. Bueche points to several sectors of energy use in which a widespread commitment is needed to revise fuel allocations and cut U.S. dependence on imported oil. How much that commitment will depend on new technology can be judged by the reader, but Bueche seems to give it first priority.

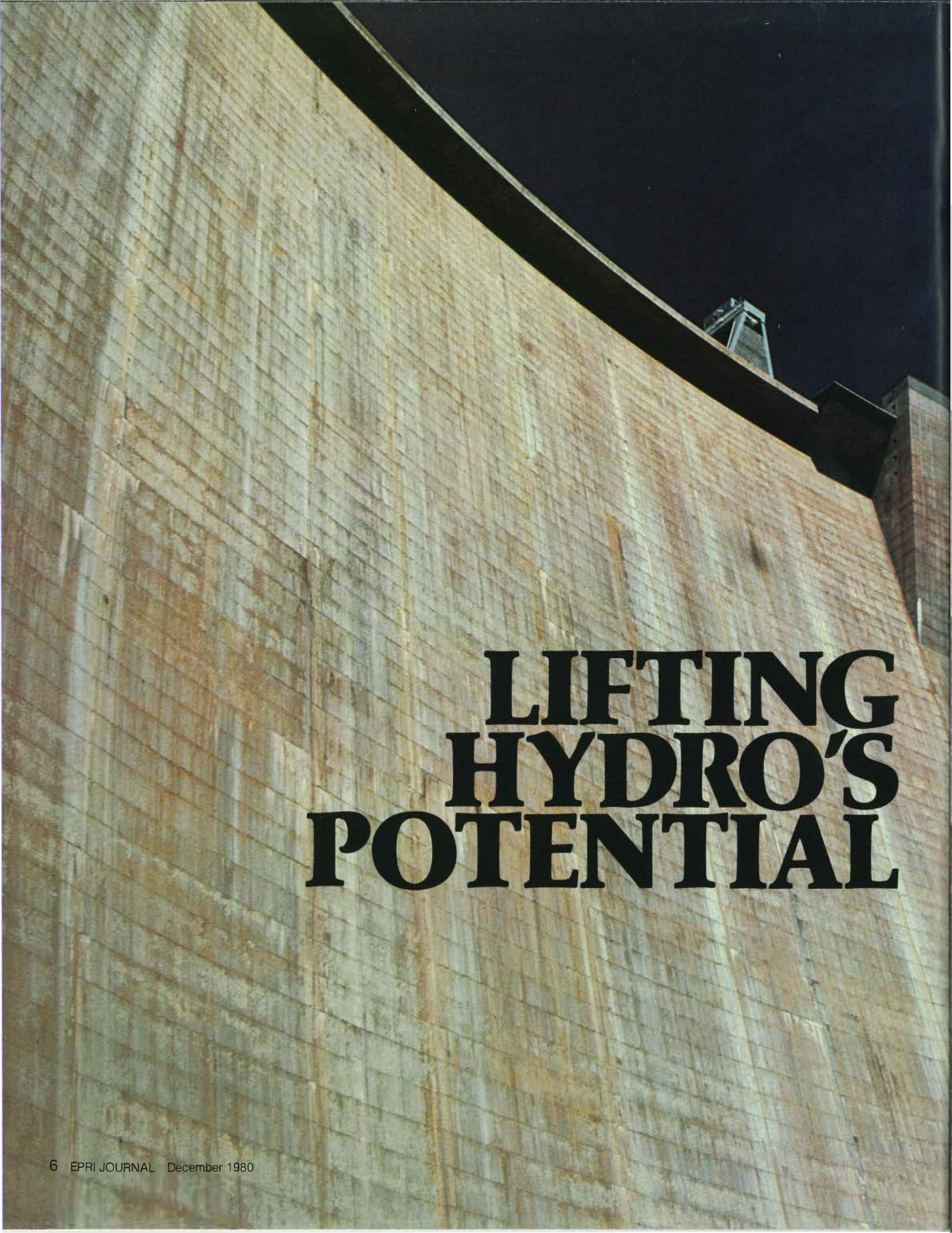
Bueche has been General Electric Co.'s senior vice president for corporate technology since 1978. His observations draw from that experience and from 28 years in research, including 13 years as director of General Electric's R&D center at Schenectady, New York. Bueche graduated from the University of Michigan in 1943 and earned a PhD at Cornell University in 1947.

Murarka

Bueche

Giovanni

Ferreira



LIFTING HYDRO'S POTENTIAL

Falling water powered the nation long before coal, oil, gas, or uranium ever did. From the beginning, gristmills and sawmills clustered around the falls on American rivers and streams. By the 1880s electricity-generating stations had joined the mills. In the 1930s huge hydroelectric projects were instituted to harness the tremendous potential of the nation's largest rivers. But by the 1940s large central steam plants fired by coal, oil, and gas began to turn out cheaper power.

Although large hydro projects were still economical, places to build new projects of such size were becoming increasingly scarce. Meanwhile, smaller hydro plants became less economical to run, and across the country many small

In their search for new capacity, utilities are reevaluating the potential of both small and large hydro installations. Most of the best sites have been developed, but EPRI is finding that existing sites can be renovated or expanded. Moreover, many sites that were once economically unattractive can now be developed to make the most of this national resource.

powerhouses closed, their worn-out equipment not worth replacing. Although new dams continued to be built, they were mainly for municipal water supply, flood control, and irrigation—fewer and fewer included electric power generation.

Rediscovery of hydro

Today the price of power from coal, oil, gas, and uranium is climbing steadily, reflecting sharp increases in the cost of fuel, capital equipment, operation, maintenance, and environmental protection.

New thermal plants also take increasingly longer periods of time to come on-line. And alternative power sources, such as solar and wind, are promising but need much more research and development before they can be economical. So the nation, in need of near-term, reasonably priced energy solutions, is again turning to hydro.

Hydro has much to recommend it in terms of capital, operating, and maintenance costs; fuel; technology; and environmental considerations. The falling water that powers hydroelectric plants is essentially free, resistant to inflation, and available to some extent almost everywhere in the United States. New engineering developments, buttressed by further research, are advancing hydro from a mature technology to the tough competitive status required today.

Although the choicest hydro sites were developed long ago and many other potential sites have since been dedicated to other purposes, engineers are finding that existing installations can be upgraded to provide more generating capacity (power) from the same amount of water or both more power and more energy by using the water more efficiently. A preliminary U.S. Army Corps of Engineers study in 1977 found a potential 55 GW available at existing installations—about half at small-dam sites. To capture those gigawatts, existing dams and powerhouses could be renovated to yield both more power and more energy, and nongenerating dams could be retrofitted to produce electricity as they continue to carry out their original functions. This redevelopment would save the costly construction of new dams and powerhouses. Not only can existing installations be upgraded, but new engineering techniques and ways of minimizing environmental effects will permit carefully designed hydro plants to be built at sites once considered unfeasible.

Hydro produces virtually no air or thermal pollution and no waste. The construction of new dams affects local plant and animal life to some degree, as well as water and land use, but if existing dams are only renovated and if new dams and plants are carefully planned, environmental effects should be minimal.

With advantages like these, it is not surprising that hydro is being revitalized. Hydroelectric generation now produces one-eighth of the nation's electric energy, with a generating capacity of 76 GW from 1500 plants. But hydro capacity will probably increase 50–100% by the early 2000s, predicts Antonio Ferreira, manager of EPRI's hydro projects. The federal government, state and local agencies, electric utilities, and other industries are increasingly aware of hydro's potential and have initiated numerous studies to develop hydro further. By 1981, for example, the National Hydroelectric Power Study (launched by the Water Resources Development Act of 1976) will provide data and information to help define hydro's needs and potential, as well as identify its institutional, environmental, and economic obstacles. And EPRI, which has been assessing hydro's potential and research needs on behalf of the electric utility industry, has recently instituted a hydro research program that addresses both small and large hydro projects.

Ways to increase output

Increases in hydro power and energy at existing installations can be accomplished in a variety of ways, explains Ferreira. These range from minor improvements to major alterations in structure and equipment. Because each hydro project has different site characteristics, prospective improvements require careful study before engineers can decide how best to improve a specific hydro installation.

Despite topographic and hydrologic variations from one hydro site to another, the basics of all hydro plants are the same. Water is collected in a pond or reservoir behind a dam, then conveyed through tunnels or penstocks to turbines. The falling water spins the turbines, which in turn drive the powerhouse generators. The result is electricity. The energy potential at each installation depends on two main factors: the head (difference in elevation between reservoir and tail water) and the quantity of water released through the turbines. Small-hydro installations are generally understood to yield less than 15–25 MW, usually with correspondingly low heads of 20–65 ft (6–20 m).

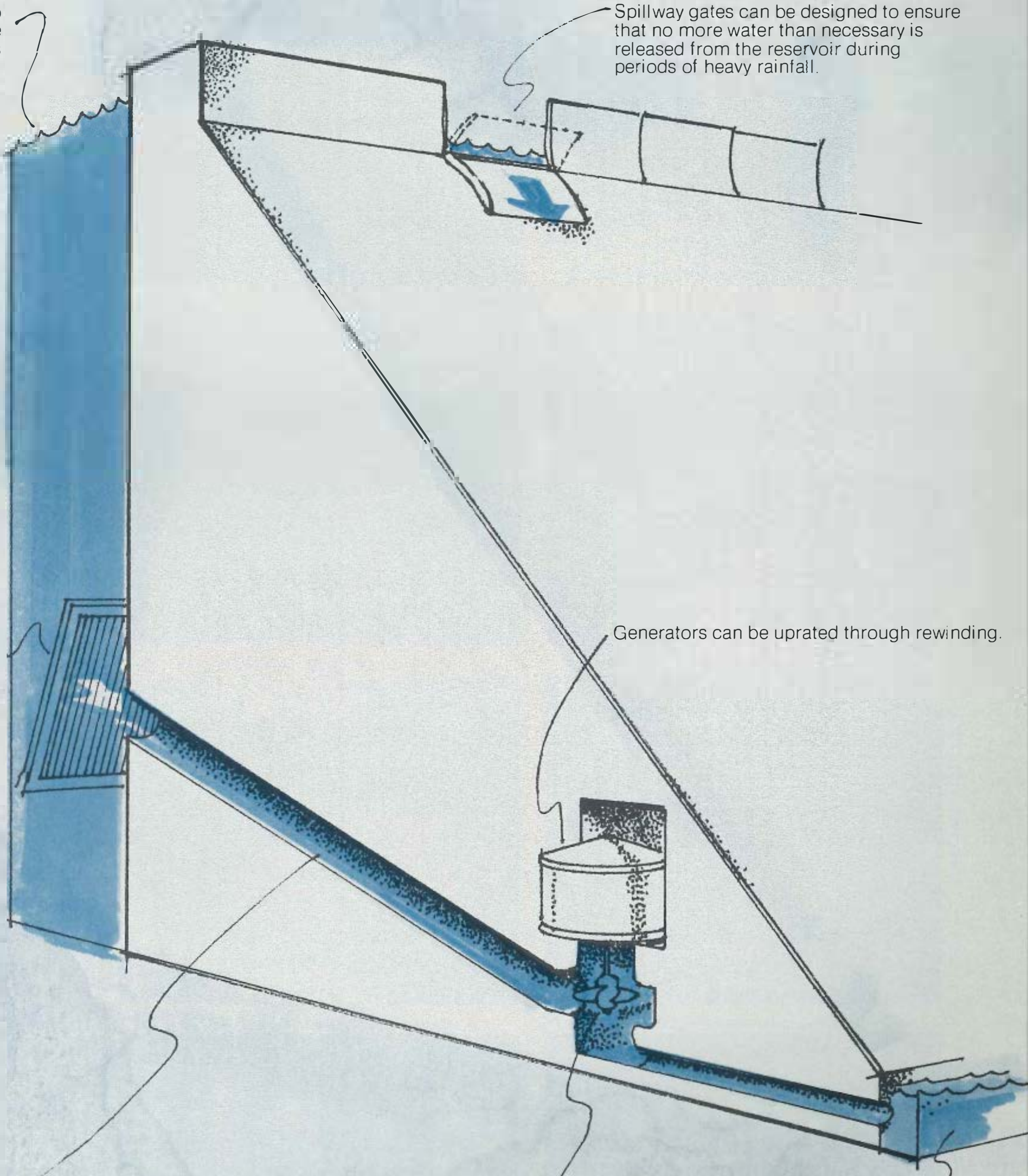
An EPRI-sponsored study by Shawinigan Engineering Corp. is now identifying ways to increase hydro plant output and suggesting research needs in the process. Some improvements are minor and can be accomplished at relatively low cost. Reduced penstock losses are one example of such an improvement—many penstocks at older dams are corroded and leaking, and their engineering design may not be the best by present-day standards. Penstocks could be redesigned and lined with materials that would cut resistance to water and minimize leakage.

Such minor improvements, while relatively low in cost, are usually of small benefit. Instead, dam owners may opt to invest in major capital improvements. These generally demand a more rigorous engineering and evaluation study for justification, but they will pay for themselves through correspondingly larger increases in capacity and energy.

One effective but sometimes costly

BIGGER AND BETTER

Although the choicest hydro sites were developed long ago, there is nothing to prevent engineers from going back and rehabilitating these sites to make better use of the resource. Both small and large installations can be reconditioned, and these improvements in turn can be incorporated into designs for new sites.



In today's energy market, a hydro plant doesn't have to be a million-megawatt behemoth to be worth renovating. Smaller installations are also increasingly attractive to electric utilities. These installations generally yield less than 15–25 MW and usually have correspondingly low heads of 20–65 ft (6–20 m). Many such plants are now being renovated and expanded, and new small sites are being developed.

improvement for increased energy output is to increase the amount of water available for power generation, either by raising reservoir water levels or by providing new storage sites. The head at a dam may also be increased by lowering tail-water levels at the bottom of the dam.

Better water control is another relatively costly but effective way of improving hydro plant efficiency. Heavy rainfall, for example, may make more water available than the turbines can handle or the dam can hold. The excess water must be allowed to spill over the dam through special gates, thereby losing potential electricity. Better gate design could ensure that no more water is released than necessary, but installation of additional turbines would permit hydro plants to use the excess water to generate additional electricity.

At other times, water must be discharged from the reservoir for environmental or recreational purposes. The amount of water to be discharged may be too small for the plant's turbines to accommodate efficiently, so the released water must bypass the turbines, again wasting energy. The installation of smaller turbine units for these occasions would enable the use of water that otherwise would be wasted.

Improved means of controlling water flow through the turbines themselves can also increase hydro plant efficiency, according to Ferreira. In some plants, turbine output is controlled by the angle of the turbine's blades or by a wicket gate (a venetian-blind-like apparatus that regulates water flow into the turbines). In the past, blade angle and wicket gates were controlled by either manual or electric means. Today, solid-state governing equipment can provide far more accurate control and hence improved efficiencies.

Besides better control of water flow through the turbines, plant efficiency can also be improved by uprating hydro generators through rewinding. Worn turbines may be completely replaced and perhaps they may be upgraded to a higher level of output.

These efforts to increase plant output must be evaluated on a site-by-site basis. One innovation that may reduce costs at small installations is standardization of equipment, such as the turbines. Until recently, turbines were custom-designed for each site, small or large. But several manufacturers have introduced standard designs suitable for certain smaller hydro projects. This lowers initial capital costs and should lower maintenance costs, making small hydro more attractive to prospective developers.

Engineers can also expand hydro output by installing generating capacity at such nongenerating sites as municipal water supply and flood-control dams. This imposes additional research requirements; for example, to make use of existing dams, inexpensive but safe and reliable means of building waterways around, through, or over these dams must be developed. Such construction can be difficult because when the area near an existing dam is excavated for erection of a powerhouse and turbines, special care must be taken so that no part of the dam or its foundation is weakened.

Pumped hydro

There are also special research needs for pumped hydro. This is an energy storage technique rather than a primary energy resource, as is conventional hydro. Less costly off-peak electricity powers a pump-turbine to move water from a lower to an upper reservoir, separated by 300–1200 ft (90–360 m). When electricity demand peaks, the water in the upper reservoir is let down through the turbines to the lower reservoir, thereby generating electricity at a lower overall cost than many other peaking options.

Pumped hydro is being used in numerous places in the United States. The generating capacity for conventional aboveground pumped storage is currently 13 GW; another 5 GW are under construction. However, suitable sites are becoming difficult to find and license. A practical alternative is underground pumped hydro (UPH), in which the lower reservoir is replaced by subsurface tunnels or chambers. By putting one reservoir underground, the environmental impact of a hydro plant can be greatly reduced.

Potomac Electric Power Co. (Pepco) has recently completed a joint UPH feasibility study with EPRI and DOE. To achieve a substantial amount of power, a large—and costly—underground reservoir would have to be mined. Results indicate that a deeper and therefore a smaller reservoir could provide a higher head, achieving equivalent power at a lower overall project cost, explains Ferreira. However, today's pump-turbine technology is limited to heads of about 2200 ft (670 m), much less than the 3500–5000-ft (1070–1525-m) head range that would make the 2-GW plant proposed in the Pepco study an economically viable project. To reach the required head with current turbine designs, the Pepco study proposes using a two-step pumping-generating plan. A pump-turbine that could operate at higher heads could eliminate this two-step operation.

EPRI and DOE are now planning to jointly sponsor the design of a high-head pump-turbine capable of attaining the 5000-ft head; a model of the turbine will also undergo extensive testing. The turbine will have to bear up under technical problems aggravated by the high head, including increased cavitation (metal erosion caused by high water velocity) and metal fatigue. While this high-head turbine is being developed, excavation methods for the necessary underground caverns should also be improved, and the cost and safety aspects of deep underground powerhouses and shafts more thoroughly confirmed.

Institutional hurdles

Although there are many ways to engineer increased hydro capacity, certain institutional problems associated with hydro power resist engineering solutions. Of particular concern to hydro developers is the cumbersome licensing process that must be concluded before construction of a power project begins. One agency, the Federal Energy Regulatory Commission (FERC), issues licenses for nonfederal hydro projects, but the licensing process itself is a thicket of federal, state, and local regulation. This can easily stymie hydro developers, particularly developers of small-scale hydro projects, who may find the preliminaries just too expensive.

Most of these regulations deal with environmental protection and land use, and all are well-intentioned. When hydro capacity is expanded at existing dams in such a way that reservoir water levels and downstream flows remain relatively unchanged and little new construction is required, the effects on the area's environment and land use should be minimal. But there are greater effects at hydro projects where reservoir levels and downstream flows are materially altered.

When water is held in a reservoir for storage during periods of high flow and released during periods of low flow, the fluctuation in water levels leaves reservoir shorelines alternately flooded and exposed. This can affect recreational and sometimes commercial use of the reservoir shoreline, and it may also affect the local ecosystem. Downstream flow variations, caused by either daily or seasonal water release, can produce similar effects on downstream areas. These effects are normally limited to the streambed itself; moreover, the presence of a reservoir can frequently reduce the variability in flow. Power plant operation can also be modified to restrict fluctuation of water levels.

Another effect related to hydro development may be downstream water temperature changes caused when colder water is drawn out of deeper levels of a reservoir and introduced into downstream flows of higher temperature.

Release of water with lower dissolved oxygen content into the downstream flow may also occur. These phenomena may affect fish and plant life, but again, they can be mitigated by proper engineering so that water is withdrawn from the reservoir at levels where temperature range and oxygen content are likely to be acceptable.

Dams themselves are clearly a barrier to fish migration, but fish ladders, fish collection elevators, and other arrangements can bypass the problem, although these arrangements can be costly for small hydro projects. Project construction may disturb archeological sites or historical sites, particularly in the eastern United States. Such potential hydro projects may require plans for site preservation.

Environmental and land-use concerns are certainly valid, and the engineering community continues to develop solutions to protect these interests. But a major institutional problem facing developers is the sheer number and variety of laws and regulations that need to be satisfied, and the long periods of time and considerable expense required for compliance. This is especially intimidating for developers of small projects.

At the federal level alone, some of the principal laws that affect licensing are the Federal Power Act, the National Environmental Policy Act, the Fish and Wildlife Coordination Act, the Endangered Species Act, the Historical Preservation Act, the Water Pollution Control Act, and the Federal Land Policy and Management Act of 1976.

Federal agencies that have to be contacted in the licensing process include the Fish and Wildlife Service, the Environmental Protection Agency, the Army Corps of Engineers, the Department of the Interior, the Forest Service, and the Bureau of Land Management. Miscellaneous state agencies concerned with such areas as water quality, water rights, and dam safety must also be consulted, as well as local agencies in charge of zoning, property acquisition, and taxation.

Some of the laws and agencies overlap in jurisdiction. "All in all, it can take from two to four years to get a license, whether for a small plant or for a large plant," says Ferreira.

The federal government is aware of this impasse. Under the Public Utility Regulatory Policies Act of 1978, efforts are being made to simplify licensing procedures for small new projects, as well as for small hydro at existing nongenerating dams. FERC has already instituted short-form licensing procedures for a range of small hydro projects and recently proposed exempting from a FERC license those projects at existing sites having a proposed capacity of 5 MW or less. Even simplified licensing procedures, however, do not exempt hydro developers from meeting environmental regulations, and more research is needed.

Another institutional concern associated with hydro development is insurance, particularly as older hydro projects are rehabilitated and as nongenerating dams are converted to electricity generation. Recent dam failures have inflated the price of dam insurance, and this tends to discourage small-scale hydro development. "We should strive for the goal of zero dam failures," emphasizes Ferreira. Reliable sampling and materials evaluation for existing dams must be devised to permit accurate safety analyses. To improve safety records, design and monitoring procedures for new dams, as well as operation and maintenance procedures for existing dams, must be developed.

Hydro feasibility

Even where utilities have a reasonable chance of meeting hydro's institutional requirements, development can still be thwarted by economic and technical requirements. Each hydro site is unique, and each utility's situation is different. Careful evaluation of existing structures, new capital investment, operation and maintenance costs, and environmental constraints must be given to individual projects to make certain they are feasible. Full-fledged feasibility studies by qualified firms will arrive at the necessary answers, but these studies are costly, and some preliminary screening of potential sites is necessary before larger studies can be made.

Screening studies, however, also present problems. "Many small utilities throughout the country have existing dams, other impoundment structures, and water supply aqueducts or canals in their system areas," explains Ferreira. "But most of these small utilities lack the staff or the technical expertise to screen the numerous sites on their systems to establish if any have sufficient technical and economic feasibility to merit further consideration. Even a large utility with in-house technical expertise seldom has sufficient staff to analyze the large number of sites on its system," concludes Ferreira.

With these limitations in mind, EPRI has prepared a relatively simple, inexpensive methodology for first-level screening of small-hydro sites. The procedure, developed by Tudor Engineering Co., will permit utility engineers, managers, and administrators to inventory possible sites, analyze their potential, rank them in order of technical, economical, and institutional feasibility, and select one or more for further investigation. The procedure can also be used to analyze the feasibility of hydro at a specific site compared with alternative means of power generation.

Two screening techniques are described in an EPRI manual. The first is a simplified step-by-step analysis when an approximate estimate of power costs and benefits is required without much reference to physical site characteristics. The second is a detailed preliminary analysis that considers site characteristics and determines power output in greater detail. Information on hydro power plants and civil construction costs is presented, together with sections on major environmental and institutional factors.

The results of both techniques have been checked against several detailed small-hydro engineering feasibility studies, and consistency has been reported. Once first-level screening studies have been completed, utilities can decide whether to engage qualified technical personnel for more detailed feasibility analyses.

Hydro power has further potential, but if utilities are to fully achieve that potential, further research must be invested in expanded efficiency and capacity, reduction of operation and maintenance costs, and resolution of environmental issues. Compromises must be made to accommodate the difficulties associated with licensing and insuring these facilities. Financing must be arranged to overcome the high front-end costs of feasibility studies, capital equipment, and the licensing process.

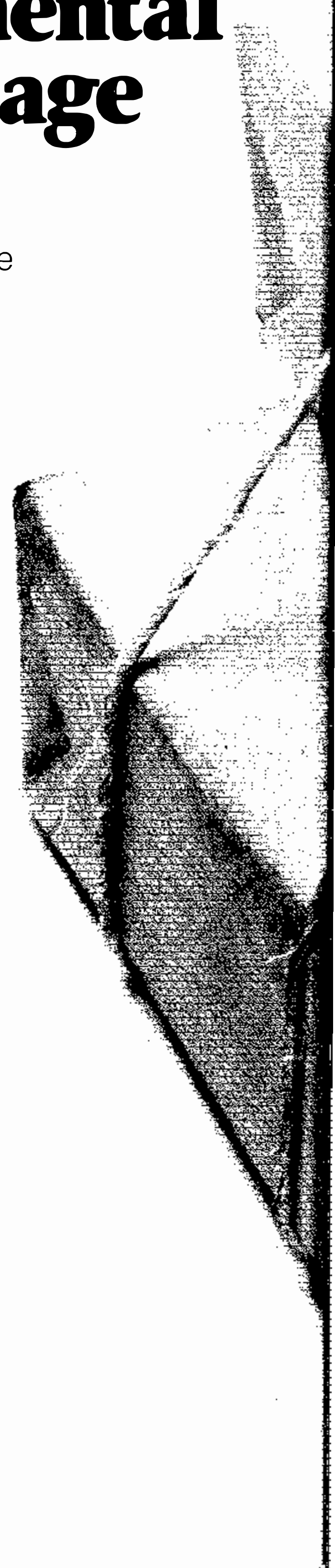
Over the coming years, EPRI's hydro program will address many of these concerns, along with others pointed out by utilities, consulting engineers, universities, laboratories, and government agencies at such forums as a recent EPRI hydro workshop. As utility needs in hydro technology are identified and ranked by priority, EPRI can help make the hydro option more accessible to utilities. Hydro's advantages—its resistance to inflation, its independence from rising fuel costs, its relative freedom from pollution, its renewability, its availability, and its proven technology—are compelling, especially to electric utilities restricted in their energy alternatives. And as the price of energy from oil, gas, coal, and uranium rises, the falling water that powered the nation from its earliest days makes more and more sense.

This article was written by Nadine Lihach. Technical background information was provided by Antonio Ferreira, Energy Management and Utilization Division.

Where hydroelectric power plant dams are barriers to fish migration, fish ladders and elevators are providing the necessary bypass for the fish to move upstream. This fish ladder is at Western Massachusetts Electric Co.'s Turners Falls plant on the Connecticut River.

IEC: Streamlining the Environmental Control Package

Delivering energy that meets all the various criteria of environmental acceptability has meant the progressive addition over the years of one control device after another. This piecemeal approach has taken its toll on the basic power plant and paved the way for a more integrated systems approach to emissions control. In the future, IEC designs are expected to reduce both capital and operating costs and improve the availability of coal-fired power plants.



Environmental protection requirements for coal-fired power plants have been promulgated in series. As a consequence, they have been met by the electric utility industry with incremental additions of control devices. Processes to control air emissions, water and thermal discharges, or solid-waste disposal, for example, were added at different times and as if each functioned independently. Through the years this practice continued and grew as both regulations and the equipment to satisfy them evolved.

Capital costs for environmental control—already representing as much as 40% of total plant cost—are high and rising. System operation and maintenance costs are high as well, and the growing amount of control equipment presents additional complexities in plant operation. Siting has become more difficult. Thermal efficiencies have gone down. And plant flexibility has been compromised. Plant availability has also been negatively affected. Once regulators would tolerate temporarily increased emissions or discharges, but now this can result in the shutdown of an entire plant, a very expensive proposition with the huge capital investment these plants represent and the cost of replacement power, which can be estimated at $400,000 a day for an idled 1-GW facility. The problem is a basic one: more subsystems mean more complexities and interactions, factors that can reduce overall plant performance, reliability, and process efficiency.

In response, a new approach to power plant design has evolved—integrated emissions control. With IEC, emission systems are no longer simply considered as plant add-on devices. Rather, they are regarded as an integral part of the plant—as integral as a boiler or turbine—and total plant flow requirements, air, liquid, solid-waste, and other control interfaces are being considered at the outset of design from a systems perspective.

In the United States IEC work is centered at EPRI, where a multifaceted effort involving component development, pilot


AIR QUALITY
WATER QUALITY
THERMAL DISCHARGE
SOLID WASTE DISPOSAL

plant testing, and evaluation of advanced R&D concepts is well under way. The focus is on EPRI's pilot plant test facility at the Arapahoe station of the Public Service Co. of Colorado, a pulverized-coal-fired plant burning low-sulfur western coal. Several utilities are considering similar programs on eastern high-sulfur coal.

Concentration on coal

The emphasis is placed on coal-fired facilities because these plants generate most of the electricity produced in the country today. And by the year 2000, they are expected to account for an additional 350 GW of domestic capacity. Their operation is therefore critical to the national energy supply.

Yet while our reliance on these plants grows, their operation is being affected by an almost inexhaustible list of federal, state, and local environmental legislation and regulation, including the Clean Air Act and its amendments, the Toxic Substances Control Act, the Clean Water and Safe Drinking Water acts, the Resource Conservation and Recovery Act, nonattainment standards, and effluent guidelines. As these regulations have been evolving and increasing in sophistication and stringency, the traditional engineering approach to utility plant design has remained the same: divide the plant into major subsystems, develop performance standards and control equipment for each, then interface.

"The historical approach to complying with environmental requirements has been to add on devices in a kind of daisy chain effect as the regulations come forth," comments Dan V. Giovanni, air quality program manager in EPRI's Coal Combustion Systems Division. "But the consequences of this have proved highly undesirable, especially when the operation of the power generation equipment is tied to the availability of control equipment. We've simply gotten to the point we can no longer look at regulations individually. We must look at them as a composite and design systems that address them as a composite. And that's exactly what the IEC approach does."

This assessment is supported by numerous others, including Kurt Yeager, director of the Coal Combustion Systems Division: "Continuation of the historical approach in which emission controls are viewed as parasitic, add-on devices can only be expected to lead to increased cost, poorer reliability, and impaired operating opportunities."

Advantages of IEC

Siting, improved flexibility in plant operations, reduced control costs, and improved overall plant availability and reliability are primary advantages of IEC over the add-on approach. Siting is facilitated because IEC can provide a more accurate total specification for a plant's anticipated control capability. By the same token, the preconstruction review process for new plants is helped as well. Flexibility is improved in terms of load changes, safe low-load operating limits, and simplified startup and shutdown operations.

Capital requirements can be reduced up to $100/kW of output (5–10% of total plant cost), operation and maintenance costs by 0.5–1.5 mills/kWh, and water costs in proportion to reduced consumption—about 0.5–1.0 gal/min for each MW of capacity. Plant availability may be expected to increase up to 5% as well, and with an improvement in the collection of pollutants, siting restrictions are minimized.

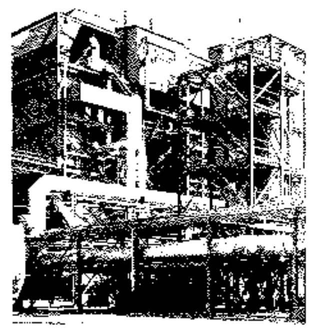
IEC can also improve a plant's thermal efficiency up to a few hundred Btu/kWh by reducing pressure drop across the system, minimizing or eliminating pumping and flue gas reheating requirements, and demanding less auxiliary power. This can mean significant savings, considering that a heat rate penalty of 100 Btu/kWh over the life of a 1-GW plant represents a capital cost of approximately $25 million.

"We're not saying that the IEC approach can or will give immediate help to the simpler plants in operation today,"

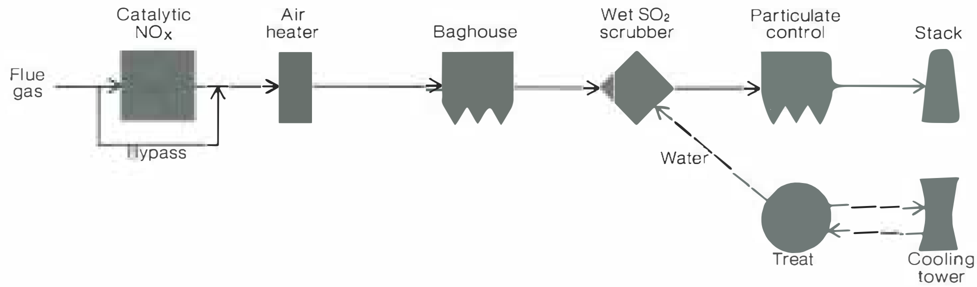
The goal of EPRI's IEC effort is to produce engineering design guidelines for the selection, configuration, and operation of environmental control equipment. This involves determining which control equipment works best in tandem with other control equipment under different operating conditions and the order in which this equipment should be arranged to perform most efficiently. The IEC pilot plant at Arapahoe has the flexibility to test all the possible equipment configurations illustrated.

To date EPRI has identified five basic equipment configurations, the first three of which it believes have the widest applicability. These configurations differ from one another primarily by the equipment used for particulate control and for SO_2 control.

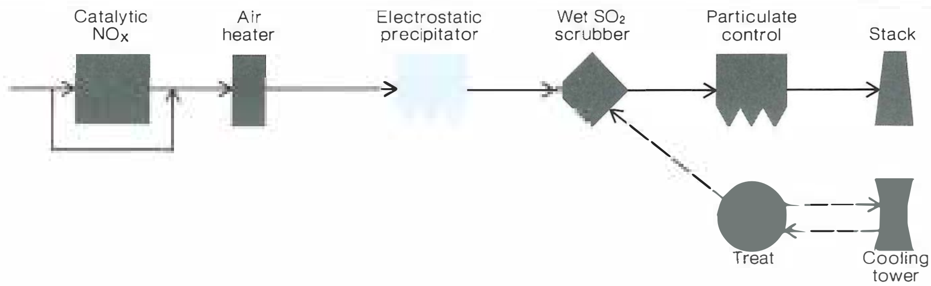
All five configurations will be tested with and without catalytic NO_X control, with and without regenerative and direct flue gas reheat, and with a closed-loop wet-cooling tower.



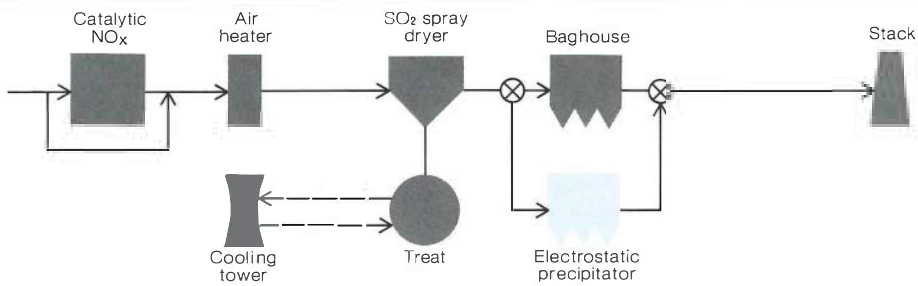
Major IEC research is conducted at EPRI's Arapahoe test facility at the Arapahoe station of the Public Service Co. of Colorado. This IEC installation is one of five independent pilot plants that operate on slipstreams from a 110-MW pulverized-coal-fired boiler.



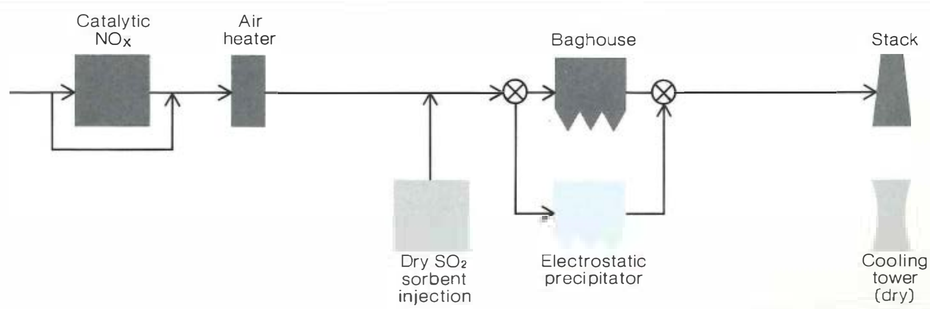
1 A baghouse for particulate control and a wet scrubber for SO_2 control.



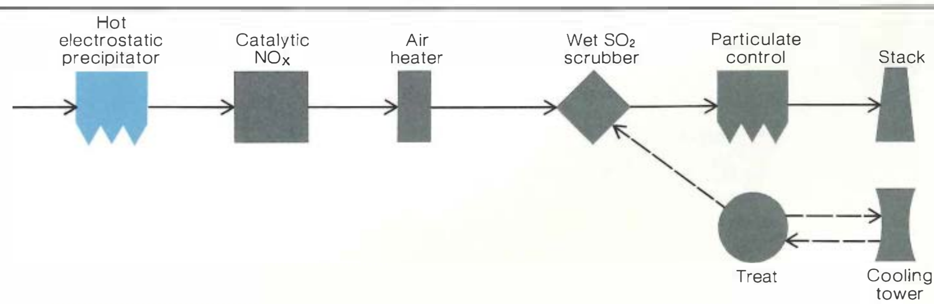
2 A precipitator or a secondary particulate control device with a wet scrubber.



3 A baghouse or a precipitator with a spray dryer for SO_2 control.



4 A baghouse or a precipitator with dry sorbent injection upstream of the baghouse/precipitator for SO_2 control.



5 A hot precipitator with a wet scrubber says Giovanni. "We are saying that IEC offers distinct advantages over the add-on philosophy, and with the new environmental constraints, it can help ensure that new plants maintain (and perhaps improve) the flexibility these existing, simpler plants now have."

Although the IEC approach is relatively new, it is not unique to EPRI. It is practiced in Japan when system complexity becomes a problem. In the United States, it has recently become a focus of attention at the Tennessee Valley Authority; however, the emphasis at TVA is on retrofit rather than new plants. "Our program is currently looking more at the conceptualization and modeling aspects of integrated emissions control than at actual hardware," explains Gerald Hollinden of TVA. "We're working on designs first, to find the best one, and then we'll go to the actual pilot plant itself."

After an initial study of pollutants and integrating systems (scheduled to be completed in February) and before construction of a pilot plant, TVA will develop a computer model that "will try to think two to three years ahead so that when we do capture a new pollutant we can handle the by-product pollution as well."

The EPRI program

EPRI is initially focusing on air, water, and solid-waste control technologies on a pilot scale of 3 MW. The overall goal is to produce engineering design guidelines for the selection, configuration, and operation of environmental control equipment in the array of operating conditions a typical utility might encounter. Emphasis is not only on the emissions control capability of the various configurations but also on the operating and cost implications of these strategies.

Pilot plant testing at Arapahoe has just begun. Design work was completed in 1978, construction began in 1979, and limited operation started this year. The total complex is expected to be completed in 1982. Beyond this, EPRI is planning for the demonstration of the technology on a commercial scale.

At the present time, all basic systems are in at Arapahoe (foundations, ductwork, controls, and the like), as well as a postcombustion catalytic NO_x system and an air preheater. Now being built and scheduled to begin operation in mid-1981 are an SO_2 spray dryer, a baghouse, a wet SO_2 scrubber, and a dry sorbent SO_2 injector. During 1981–1982, both a cold and a hot electrostatic precipitator and a cooling tower with water treatment capability are to be installed. Each component is self-contained, skid mounted, and relocatable; this modular design permits reconfiguration for evaluation and comparison.

"Arapahoe is far more than any utility will hope to have," explains Hollinden, "and it is imperative that we don't get information on each piece of control equipment separately. Rather, we need to know how it operates on an integrated basis: 'This is the way these controls fit together, and this is what you get.'"

The first step in EPRI's program was to assemble an in-house group of specialists, representatives of each of seven programs within the Coal Combustion Systems and the Energy Analysis and Environment divisions. IEC research needs were initially assessed. Then four program priorities were established for the Arapahoe effort.

- Investigating individual processes and integration factors over a range of typical equipment designs and operating conditions

- Monitoring and assessing the impact of simulated startup, load swings, upset conditions, and major component failures on various equipment configurations, and defining hardware needs

- Developing a range of concepts for integrating conventional control equipment to improve system operation and reduce overall costs (e.g., using cooling-tower effluent as SO_2 scrubber influent)

- Proving or refining new hardware and software and developing new controls and continuous performance-monitoring equipment

Five basic options

With these priorities, five basic equipment configurations were identified, three of which were thought to have the widest applicability. These selected systems are distinct from one another in the equipment they use for particulate control and SO_2 control, and they will be tested first, both comparatively and in terms of options within each.

The first configuration will use a baghouse and a wet scrubber. The second will use a precipitator or a secondary particulate control device with a wet scrubber. And the third will use a baghouse or a precipitator with a spray dryer. All these configurations will be tested with and without catalytic NO_x control, with both regenerative and direct flue gas reheat, and with a closed-loop wet cooling tower.

"Eventually," says Giovanni, "we think the IEC approach will be inevitable because of environmental requirements and the complexity of the equipment re-

IEC SYMPOSIUM

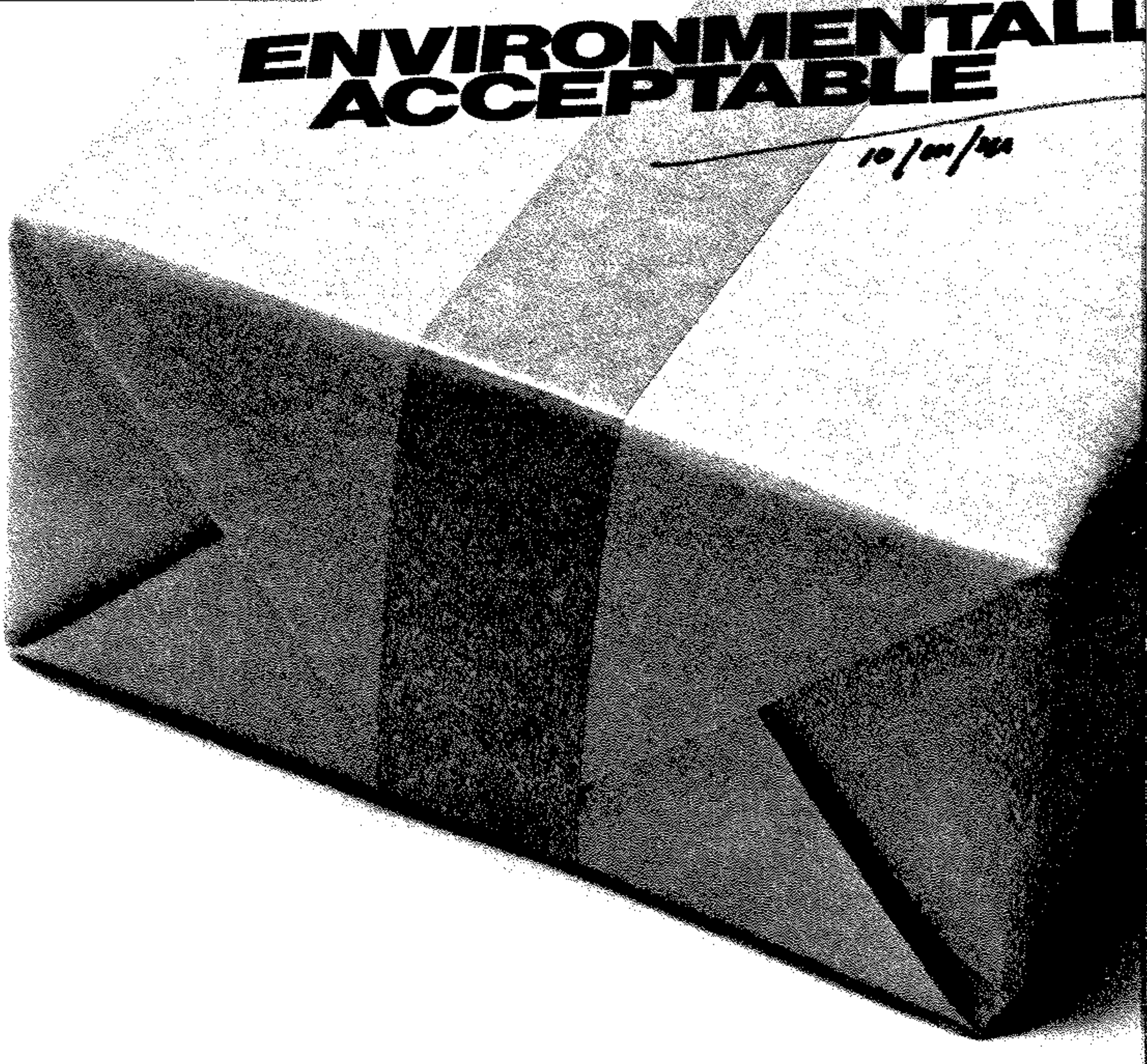
A symposium on the integrated systems approach to emissions control for conventional coal-fired power plants will be cosponsored by EPRI, the American Society of Mechanical Engineers, and the Air Pollution Control Association. The meeting will be held in Denver, Colorado, February 22–25, 1981.

The first two days will be devoted to four sessions: motivation and scope of IEC; air quality control; end-product management utilization; and advanced technology options. The third day will include a tour of EPRI's Emissions Control and Test Facility, where the IEC pilot plant is located. Further information can be obtained from Dan Giovanni, EPRI program manager for air quality control (415-855-2442). □

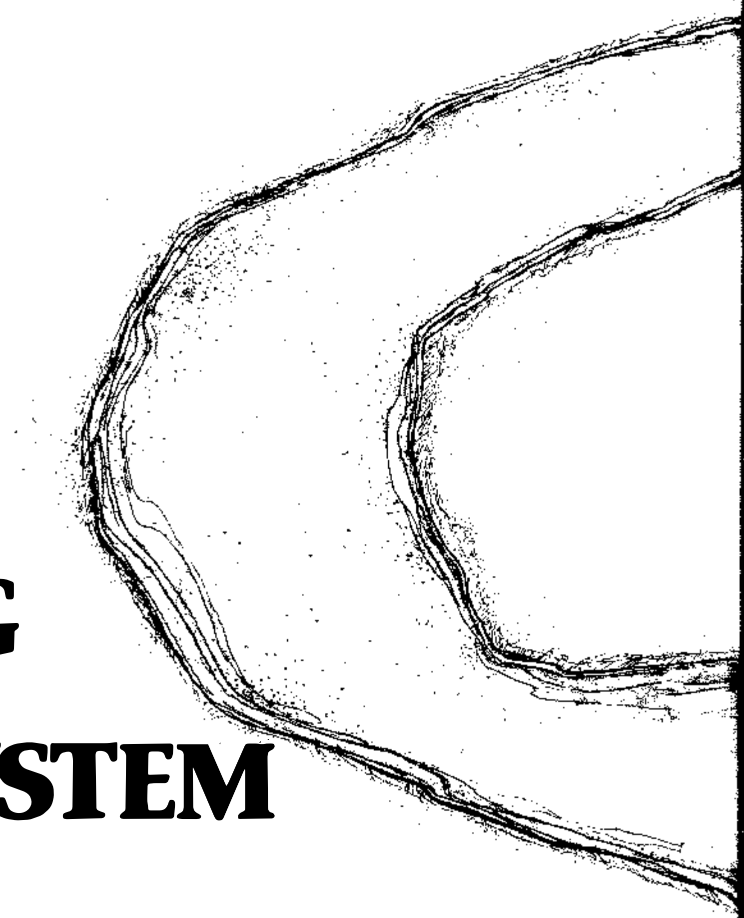
quired by the regulations. But this approach is in contrast to traditional engineering practices. What we're trying to do, in effect, is to accelerate development, to produce specific guidelines that indicate which configuration would be the best choice for a particular situation, and how each should be implemented. And we're trying to do this at the pilot plant level so we produce real results that can be transferred quickly and directly to large, full-scale operation."

This article was written by William Nesbit. Technical background information was provided by Dan Giovanni, Coal Combustion Systems Division.

ENVIRONMENTALL[Y] ACCEPTABLE



The electric power industry draws water from rivers, lakes, and oceans, principally for condensing the steam that has turned the turbine-generators. Fish in this cooling water can be stressed by system mechanisms and temperature changes. EPRI-sponsored research is trying to reduce these stresses and compensate for the adverse effects on aquatic life.



PROTECTING FISH FROM COOLING-SYSTEM EFFECTS

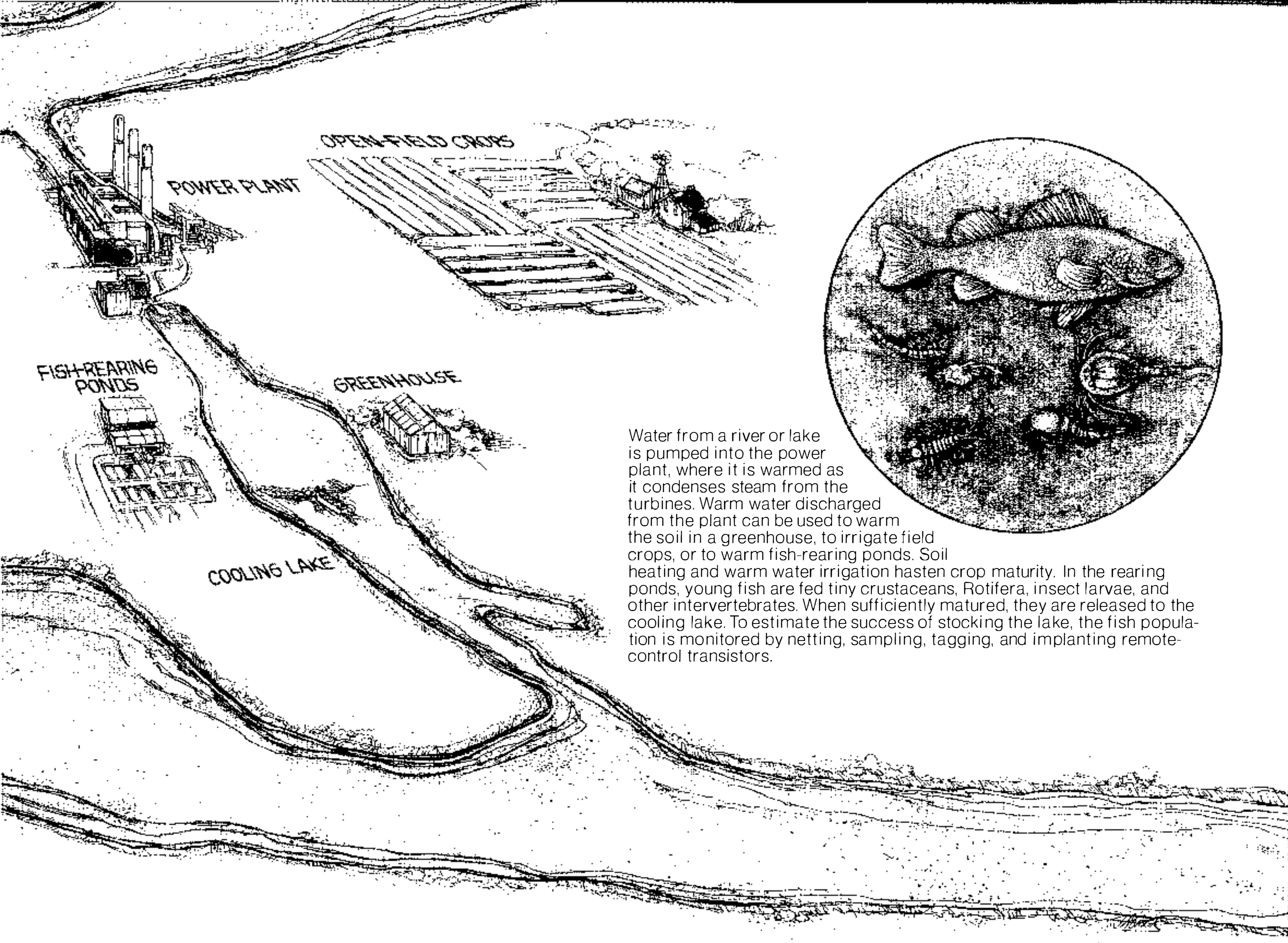
Water that is pumped through an electric power plant cooling system undergoes physical and chemical changes that can stress the aquatic ecosystem, particularly the fish population. Researchers have identified the nature of short-term effects of these stresses, and environmental laws and regulations have been established to minimize possible long-term changes in aquatic ecosystems.

EPRI has organized a number of research projects that focus on ways to protect (and enhance) aquatic ecosystems near power plants. The ultimate goals are to design cooling-water intake and discharge systems that lessen environmental impact and to develop beneficial uses for warm waste water. In charge of this research is the staff of the Ecological Effects Program, Energy Analysis and Environment Division, with cooperation from other divisions, notably the Water Quality Control and Heat Rejection Program of the Coal Combustion Systems Division.

Nature and the condenser

Of two main types of power plant cooling systems, the once-through is the most common. In the once-through system, cooling water drawn from a body of water is pumped through hundreds of tubes in a steam box, or steam condenser. The steam, which has turned the turbine-generators, must be converted to water before its return to the boiler. Cooling water pumped from the external source absorbs the steam's heat and is then pumped back to the body of water from which it was drawn. On the other hand, in a closed-cycle cooling system, only enough water is drawn from the source to replace the water lost in the operation of the system (e.g., in evaporation from a cooling pond or a cooling tower).

Whatever the amount of water used, it is nevertheless the habitat for numerous species of animal and plant life. Water intake areas of the cooling system are therefore designed to screen out these



Water from a river or lake is pumped into the power plant, where it is warmed as it condenses steam from the turbines. Warm water discharged from the plant can be used to warm the soil in a greenhouse, to irrigate field crops, or to warm fish-rearing ponds. Soil heating and warm water irrigation hasten crop maturity. In the rearing ponds, young fish are fed tiny crustaceans, Rotifera, insect larvae, and other intervertebrates. When sufficiently matured, they are released to the cooling lake. To estimate the success of stocking the lake, the fish population is monitored by netting, sampling, tagging, and implanting remote-control transistors.

organisms. But in conventional intake designs, simple screens let through small organisms, such as fish eggs, larvae, and plankton. Larger fish, unable to escape because of the speed and volume of the intake water flow, impinge and accumulate on the screens, along with debris. Frequent cleaning is needed to keep the screens clear.

The organisms that do filter through the screens are pulled into the cooling system, where they are subjected to buffeting, pressure, and heat before being ejected. The water in which they are entrained rises 20–25°F (8–11°C) in a once-through system.

Impingement and entrainment, obviously, are ecological concerns. But they also cause engineering problems. When organisms, both dead and alive, clog filters, pipes, and pumps, they can cause a pressure drop in the cooling water. Thus, electricity consumed in pumping goes up and plant efficiency goes down. Further, bacterial slime and algae introduced by cooling water can reduce the bore size of condenser tubes by growing rapidly in the harsh yet viable environment. This biofouling can be accompanied by scaling on the inside tube surfaces, caused by the deposition of suspended solids in the water and concomitant corrosion.

Biofouling and scaling—both reducers of efficiency—are difficult to combat without frequent applications of chemicals, such as chlorine. But the chlorine and its compounds render the discharged cooling water potentially harmful to an ecosystem. For this reason, regulations that are part of the Clean Water Act of 1977 require utilities to limit the use of chlorine. Under extreme conditions, where biofouling and scaling are out of control, expensive plant shutdowns are necessary for the cleaning of condenser tubes by mechanical methods.

Designing for minimal impact

With impingement, entrainment, thermal stresses on ecosystems, and biofouling and scaling to be considered, designing effective cooling systems is not an easy assignment. So far, most progress is at the initial research stage, but some engineering changes have been made and are being tested.

One engineering development is a porous dike, an intake screen inexpensively built of suitably sized pieces of rock that slow the water speed at intake areas and reduce the impingement of fish. This type of screen is being tested at New England Power Co.'s Brayton Point station. Although some clogging still occurs, small fish do not pass as easily through the porous dike as through earlier designs.

While more efficient screens are being developed to reduce entrainment and biofouling, researchers are also investigating ways to lessen the mortality rate among those organisms that do pass through the cooling system. A simulated cooling system has been constructed at Oak Ridge National Laboratory for the detailed monitoring and measurement of the stresses on organisms that are caused by pumps, temperature levels, and vacuum conditions.

Biofouling and scaling are doubly challenging because the addition of chemicals as a remedy can cause other problems. Even with closed-cycle cooling systems, utilities have to find ways to limit water pollution that can occur when the systems are periodically flushed out and release their corrosion-inhibiting additives with the cooling water.

Ultimately, all engineering changes depend on the outcome of the ecological studies. These studies are so new, however, that they are only at the stage of examining individual organisms or, at best, the group of organisms directly affected. Not only is statistical uncertainty high at present with regard to the particular organisms under study, but the effects on the species population and on the ecosystem have barely been researched. Initial clues so far indicate that a population and ecosystem have many natural resilience factors to compensate for impacts on small parts of the whole.

The complex aquatic world

Before utilities can make optimal decisions on siting new power plants and designing cooling systems, they must acquire better information about the workings of the aquatic world. Only when the aquatic environment has been characterized and understood can the effects of external changes on that environment be evaluated.

The first step is to monitor and measure flora and fauna so that computer simulation models can be constructed. The second step is extrapolation of the monitoring data by the computer model to permit dual experiments in the laboratory and in the body of water. Thus, the third step—prediction of environmental effects—can be made on the basis of reliable data and experimental results that have been collected in sufficient number and over a period of time long enough to be meaningful.

In addition to the studies of flora and fauna, other aspects of cooling-system effects must be considered, such as the body of water on which a power plant might be situated (e.g., river, lake, or estuary), the quantity and quality of water to be drawn, and an ecosystem's sensitivity to cooling-system operations. It is then that the design of a cooling system can be chosen.

The first stage of study, the regular sampling of flora and fauna and the tagging and monitoring of fish, may take one or two years. This work is expensive, time-consuming, and beset with difficulties. For example, sampling nets tear easily and monitoring instruments are not as reliable as one could wish. So there is a great need for innovative designs for nets and instruments that are rugged and accurate, as well as nondestructive to fish.

The second stage, the laboratory and field experiments, can give tangible evidence of effects of such chemicals as chlorine on various types of fish. It is also particularly important to characterize fish spawning and migration patterns, especially in estuaries and sheltered coastal areas, where any environmental disturbance has the potential of doing great damage. These spawning areas are critical to the existence of certain species. Yet the task of characterization is anything but simple—it takes a long time to understand some fish species. Experiments cannot always replicate their life cycles. The striped bass, for instance, has an average life span of 12 years, with a maximum of 20 years. If one generation is removed because of an external impact that destroys a year's supply of eggs, the effect on that species (in addition to the ripple effect up and down the food chain) can be serious.

Fortunately, fish and other organisms compensate naturally for decreases in their populations. Either more young are produced or the normal number of young have a much higher survival rate. However, this compensation is not necessarily automatic, and it, too, is the subject of research. Only when the results of the various research projects are conclusive will the third stage be possible—accurate prediction of cooling-system effects.

Advantages of warm waste water

Warm water discharged in large volumes from cooling systems was once suspected of being a major ecological danger. While there are some dangers, it can now be shown that with good management, warm water can be beneficial. For instance, it can be used to boost fish production both in hatcheries, which supply fish for food and for sport, and in the water source, thereby helping to replace the native fish lost in the intake section of the cooling system. At this time, four utilities have used discharge water in this manner and are supporting commercial operations that supply oyster seed, salmon smolts, and edible-size catfish to the market: Long Island Lighting Co. (Long Island Oyster Farm in Northport, New York); Pacific Gas and Electric Co. (International Shellfish Enterprises in Moss

Landing, California); Central Maine Power Co. (Maine Salmon Farm in Wiscasset, Maine); and Texas Electric Service Co. (Cultured Catfish, Inc., in Colorado City, Texas). For locations without a natural body of water nearby, an artificial cooling pond or lake can be created. When warmed by discharge water, it can be stocked with popular types of sport fish.

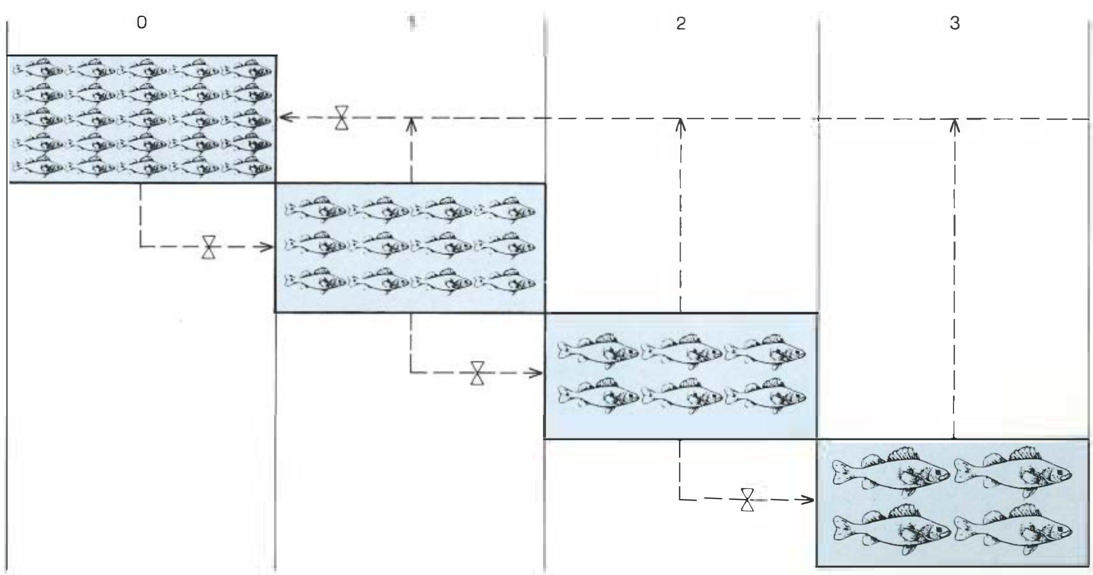
Researchers are still experimenting with different conditions related to the introduction of the fish, which is the riskiest stage of production. The young fish, about 2–4 in long, are vulnerable to even slight fluctuations in water temperature, so they are best introduced to their new environment at times of year when the natural temperature is most stable. Not only is appropriate water temperature essential but the amount of prey fish available to feed the sport fish is critical to the success of stocking ponds. Too little food or the incorrect type can result in poor fish production.

The warm water discharged from a power plant cooling system can also benefit agriculture. Research has confirmed that warm water piped to greenhouses increases production—doubling or tripling the number of harvests. Open-field crops also respond to warmth in the cold seasons. However, economic questions of constructing and operating agricultural facilities need further examination, and knowledge will be expanded by the commercial operation recently begun by Northern States Power Co. at its Sherburne County (Minnesota) power plant.

Major work ahead

Fathoming the relationship between ecosystems and power plant operations still has a long way to go. Yet the federal Clean Water Act mandates that electric utilities change their cooling systems to the "best available technology" as soon as possible. This change in technology is an engineering function, yet the engineering depends on results of lengthy ecological investigations. So far, only short-term effects are known—the local effects on fish of warm water and entrapment. Long-term effects and offsetting benefits pose the most complex questions. It is going to take time, money, and new ideas to meet the legislation that was enacted to protect the ecology and benefit the people served by the industry. ■

This article was written by Jenny Hopkinson. Technical background information was provided by Ishwar Murarka, Energy Analysis and Environment Division.



The Leslie matrix is a practical arrangement for systematically recording the age pattern of fish populations over a sequence of years. These records show fluctuations in fish populations of different ages and provide estimates of fish mortality. The number of fish that perish by human action is generally small. Compared with the natural mortality rate, that induced by power plant operation is so low that it is virtually impossible to establish its significance.

Large and detailed books are being written on energy conservation and efficiency and on fuel substitution—at a rate of about one a week, it seems. This flood of books is paralleled by the large amounts of money that we are now spending as a nation on energy conservation. There are no precise figures, but my guess is that it is over $10 billion a year at present. Much of this money is being spent by industry (about $6 billion); almost all large U.S. companies, including utility companies, now have substantial energy management programs. About $3.5 billion of the $5 billion in R&D by the automobile companies is now directed toward conserving energy with more fuel-efficient cars.

U.S. government at all levels spends about $4 billion a year on energy conservation. Tax credits account for much of this $4 billion, and sizable amounts are also being spent on such items as mass transit systems and reducing the energy consumption in government buildings. DOE's conservation program funding is about $1 billion a year, much of it allocated to grants and information programs, plus about $300 million in direct conservation R&D. I use the term *direct conservation R&D* because it's almost impossible to define the total technical effort associated with energy conservation and efficiency and with interfuel substitution. R&D on everything from biomass to nuclear fusion can be regarded as having the objective of substituting one energy source for another. Over 90% of DOE's $4 billion R&D programs are involved with energy conversion and energy use, and efficiency is a concern in almost all of them. Again, industry is spending at least as much as DOE in this area, and probably more.

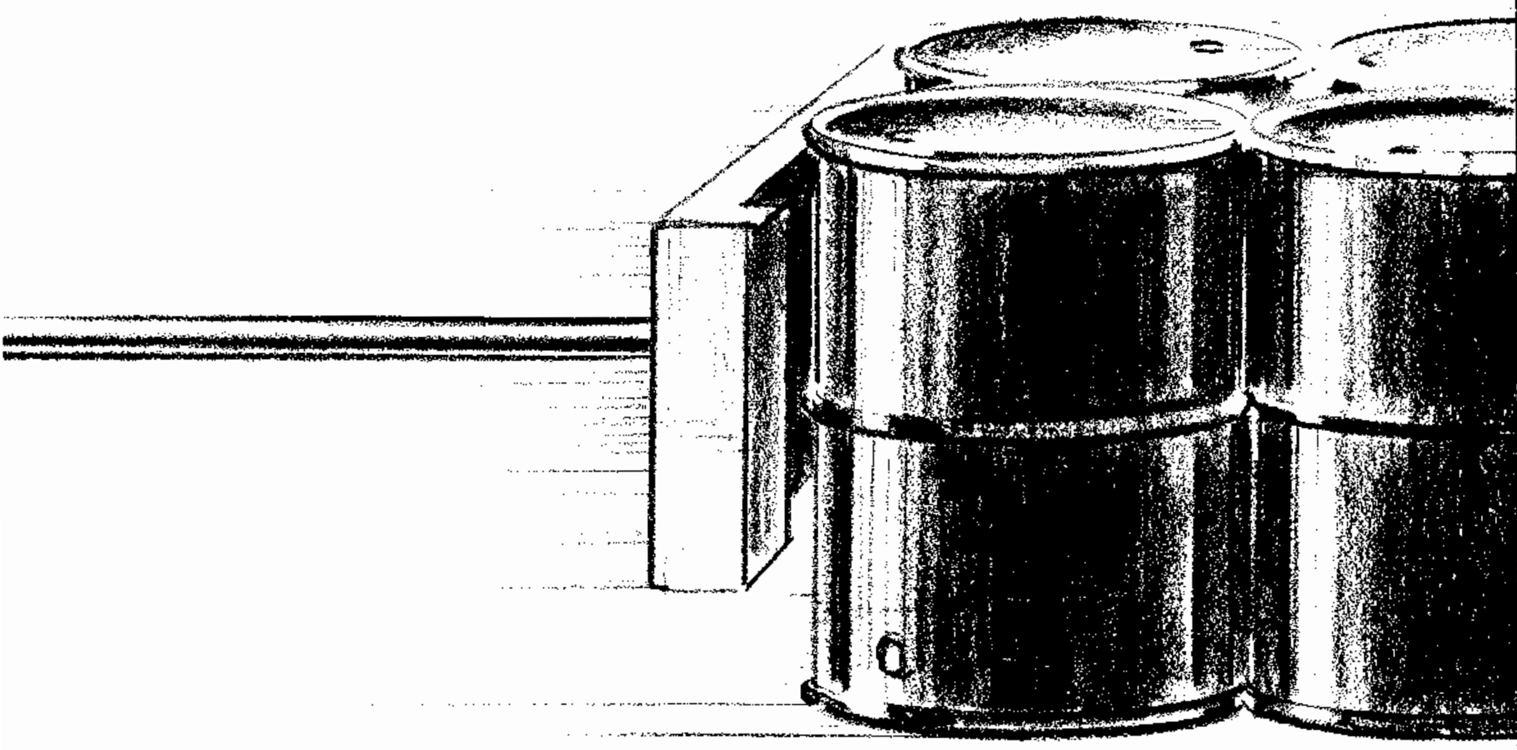
If money and a wide range of technical programs were the answer, the United States would be well on its way toward solving its energy problems. Certainly there are some encouraging signs. We did not use any more total energy in 1979 than in 1978 (78.2×10^{15} Btu), and we used slightly less oil (37.1×10^{15} Btu rather than 38×10^{15} Btu). After about 60 years of stagnation, we are finally using more coal, even though the average growth rate since 1973 has only been 4.4% per year. There are even some people in DOE and elsewhere who regard it as an encouraging sign that since 1973 we have held the growth in electricity sales to 3.1% a year. I personally do not consider that anything to be proud about; I consider it a national mistake.

Instead of congratulating ourselves on how well we are doing, let us look at a couple of key indicators about our use of oil. It has been said a thousand times, but it deserves at least one more repetition: The United States has no overall energy problem; it has an oil supply problem. The problem is illustrated by the amounts of money that we have been spending on oil in two recent years. In 1973, consumers paid about $70 billion for oil, and our oil imports cost us $8 billion. This year consumers are paying at a rate of $300 billion a year, and our oil imports will cost us about $82 billion at

ENERGY CONSERVATION, EFFICIENCY, AND SUBSTITUTION

by Arthur M. Bueche

Imported oil is a luxury whose time has come for replacement by other forms of energy. Its true cost is more than double the import price because of its effect on GNP and the rate of inflation.



current prices. What is more, our expenditures on oil as a percentage of our total fossil fuel expenditures have been going up, not down. For the first quarter of 1980, almost 80% of our total fossil fuel expenditures were for oil.

It is worth looking at the way the United States has been controlling use of oil, compared with other OECD nations. The percent changes in international oil use from the embargo year of 1973 until last year show that the United States, with a 6.5% increase, was among the poorer performers, second only to Canada (10.6% increase), whose oil prices are the lowest in the free world. France, with a 5.1% drop in oil use, was bettered only by the United Kingdom, which achieved a 13.7% drop by discovering a few gas fields and also by having the slowest growing economy in the industrialized world.

The point that I am trying to make is that as a nation, we have not begun to cut back seriously on our oil use. It can be done, because we have the example of countries like France and West Germany that have achieved it. We cannot do it by erecting roadblocks to the use of alternative energy forms. We can do it only by a national commitment, such as France has exhibited toward nuclear energy or West Germany toward coal.

To look at the problem from another angle: In plotting the cost of energy delivered to U.S. end users as a percent of GNP, we see that energy costs went from 6.5% of GNP in 1970 to 15.8% today, paced mainly by oil costs that went from 2.2% of GNP in 1970 to 9.1% today. This happened even though the energy efficiency of the U.S. economy in Btu per unit of GNP improved steadily at an average of 1% per year. If our society was in some sort of economic equilibrium with the relative costs of capital, labor, and energy in 1970, it is far away from equilibrium now.

This particular situation is going to get worse, not better. We project that over the next decade the price of oil is going to increase markedly in relation to coal and electricity. Also the price of gas will increase at 11.8% a year in constant dollars for industrial consumers, soaring relative to these other energy forms, as its price approaches parity with oil. By 1990 we project that electricity will be only 12% more expensive than oil on a direct-equivalent Btu basis, with no allowance for the improved efficiencies possible with electricity use. If it pays to substitute coal and electricity for oil now, it will pay even more 10 years from now. On the other hand, substitution of natural gas for oil, while it can save money at present, will become increasingly more difficult to justify economically, even assuming that gas continues to be readily available.

In the summer of 1980 a colloquium on planning for an energy emergency took place at Stanford University, and the main message that the press distilled out of that meeting was that the United States is not ready now to cope with a sudden cutoff of much of its oil. Of course, DOE and other groups are studying the problem, but the only way to buy security is through action ahead of a crisis to reduce our dependence on foreign oil. I made a proposal at the Stanford colloquium for planned substitution of 4×10^{15} Btu of oil by electricity in five selected end-use applications in space and process heating and in transportation.

This substitution of oil could be achieved with today's technology and, in most cases, with today's products. In space heating, we would rely primarily on heat pumps, including the recently introduced add-on heat pumps, which optimize the combined use of electricity and oil or gas. In low-temperature industrial applications, we would use electrode boilers, plus industrial heat pumps to upgrade the temperature of warm process effluents. For higher-temperature industrial applications, electric arc furnaces, annealing ovens, glass-melting furnaces, and special equipment, such as electric plasma torches for the processing of quartz, are readily available. In transportation, substitution of electricity for oil need only involve the most economically advantageous areas of railroads and local delivery vans, even though the technology for electric passenger vehicles is well advanced. I believe that a planned replacement program along these lines could be accomplished in four or five years.

Of course, in many parts of the country we would have to build more nuclear and coal-fired power plants to accomplish this much electrification. But consumers would save money as a result. For example, the current annual operating cost of heating a house with an electric heat pump in one eastern city is 75% ($806) of the cost of heating it with oil ($1077). Gas heat is still a few percentage points less expensive ($786), but we are confident that electric heat pumps will be providing the lowest operating costs within a year or two and the lowest total costs, including amortized capital costs of the heating system, by 1990. If, as we confidently expect, heat pumps with much improved performance are available by 1900, consumers will be even further ahead.

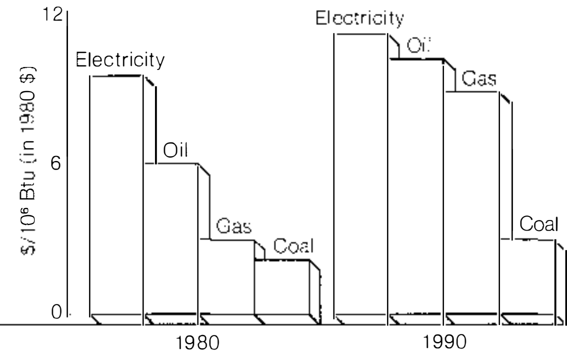
Other substitution candidates make equally good economic sense. For example, a vice president of Union Pacific recently noted that the railroad's fuel costs as a percent of revenues had soared from 4% in the early 1970s to 14% now and the company would have to give serious thought to electrification. This could save the railroad money, or alternatively, if its costs could be reduced significantly, the railroad would then be able to expand piggyback freight transport as an economic alternative to long-distance trucking. Another example of a substitution candidate is the electric vehicle: General Motors Corp. intends to introduce a model in 1984 and build up to an annual production of 100,000.

My topic at the colloquium was substitution of electricity for oil in end-use applications, but there are many other possibilities for planned substitution, such as industrial applications in which

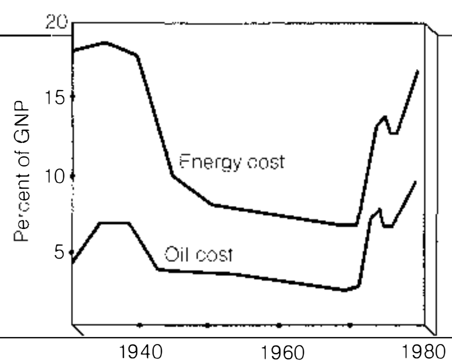
OECD OIL USE 1973–1979
(% increase/decrease)

Canada	10.6
United States	6.5
Italy	6.1
Japan	3.4
West Germany	−1.1
France	−5.1
United Kingdom	−13.7

INDUSTRIAL ENERGY PRICES



ENERGY/OIL COSTS AS PERCENT OF GNP



ELECTRICITY SUBSTITUTION FOR OIL

	Present Oil Use (10^{15} Btu)	Substitution Potential (10^{15} Btu)
Residential and commercial space conditioning	4.0	2.0
Low-temperature industrial and commercial heat	4.0	0.6
High-temperature industrial direct heat	2.5	0.5
Intracity passenger and freight transport (bus and van)	1.5	0.6
High-density rail transport	0.6	0.3
Total	12.6	4.0

the direct use of coal could be expanded. For example, the use of coal for cement manufacture is already proven and economic. With existing pulverized-coal boilers, coal can be used for making process steam in large industries, such as petroleum refining and bulk chemicals. Its use can be expanded into the smaller industries with atmospheric fluidized-bed boilers. Low-cost lignites are being eyed for electricity generation by aluminum producers. A lot of this substitution of coal could take place quickly and with relatively low capital outlays, in contrast to the production of synthetic liquids from coal, which is a longer-term and more capital-intensive approach.

In some cases, electricity and coal would substitute for gas rather than oil. We can free some of the gas used in direct-heat applications by such electric substitutions as food preparation by microwaves or paint drying by infrared heating. The gas freed can then be used to substitute for oil in industry and in residential and commercial applications. In these ways, over a five-year period we could eliminate much of the 7.4×10^{15} Btu of oil used by industry for nonfeedstock purposes. Similarly, if 25% of the homes that now burn gas could be converted to heat pumps by 1990 and 25% of new homes that might burn gas are diverted to heat pumps, we could use the displaced gas ($\simeq 1.5 \times 10^{15}$ Btu a year) to substitute for yet more oil.

One substitution for oil that must be on the minds of many electric utility executives is the question of repowering oil-fired power plants. DOE has looked at the economics of repowering, using as an example a baseload plant replaced by a completely new coal-fired plant, with full carrying charges for an idle oil-fired plant. This repowering has a small economic edge, 39.9 mills per kWh compared with 40.6 mills per kWh.

The conservation target for repowering—3.5×10^{15} Btu of oil, or 9% of our total national use—is attractive. Though repowering is an unwelcome task, electric utilities cannot honestly promote

ECONOMICS OF REPOWERING
(65% capacity factor, mills/kWh in 1979 $)

	Existing Oil	New Coal
Capital costs	9.7	13.0
Carrying costs of idle oil-fired plants	–	9.7
Fuel	30.4	12.5
O&M	0.5	4.7
Total	40.6	39.9

CONSERVATION OPTIONS
(equivalent costs per barrel of oil saved)

Attic insulation	$ 7–15
Residential heat pump	30–40
Electric vehicle	40–45
Heat recovery from power plant effluent	60–90
Active solar	80–90

electrification until oil is eliminated as the marginal fuel for producing extra kilowatthours.

There are two problems: the highly regional nature of the situation (all 80 plants now scheduled for repowering by DOE are on the eastern seaboard) and the capital costs. We cannot move the plants, but there are a number of ways in which we could solve the capital cost problem. We do not always have to build completely new coal-fired plants, as DOE assumed. Many of these plants could be repowered without replacing the boiler by adding a coal gasifier, plus the gas cleanup required by local air quality standards. If even that alternative is too expensive, in many cases repowering with coal-oil mixtures could be undertaken quite inexpensively. Several companies are planning to offer these mixtures commercially so that utilities would not even need to add coal piles and coal-handling systems. Even if boilers have to be replaced, the turbine-generators and balance-of-plant equipment could be retained, and a highly efficient coal-fired boiler, such as a pressurized fluidized-bed system, could be added.

I think that substitution of other energy forms for oil is an underused conservation option and substitution can be precisely aimed at our real energy problem. Also, energy substitution is something that can often be done easily and quickly. If we had to achieve the same results by building cogeneration plants, for example, or by finding ways to use the reject heat from electric power plants, it would be a much slower process and would cost much more. Where efficiencies can be improved quickly, as in the introduction of automobiles that travel more miles to the gallon or in the use of more efficient appliances and electric motors, we should, of course, put them into practice. Only as a last resort should we try to achieve conservation by cutting down on energy services.

The United States is accustomed to having energy available whenever, wherever, and however it wants, and I hope that we continue to demand that privilege. It would be only too easy for us to revert to the situation of much of the rest of the world—that of not knowing if the electricity will come on when we turn the switch.

We have to pay for having energy available reliably in the form in which we need it and in the place in which we need it. The energy that we eat, for example, costs 3.4 Btu in direct energy input to the farm and to the food-processing industry for every Btu consumed. This isn't waste; it's a consequence of the fact that we prefer to eat hamburgers rather than crude oil. Every energy production process has its own energy costs. To mine 100 Btu of coal and transport it to the point of use involves the consumption of about 3.5 Btu of oil. Ten percent of all our oil is consumed in refining, and about 5% of our natural gas is consumed in pipeline pumping.

Contrary to the impression given by many energy flow charts, so-called energy losses are not exclusively confined to the production of electricity, but occur in all energy production and use categories. These are not generally evidences of waste, but necessary costs of the energy system.

We should, by all means, eliminate real energy waste, where we are literally throwing both energy and money away. But we need to be selective in choosing targets for energy conservation, efficiency, and substitution. Here are two guidelines to help in that selection.

First, concentrate on replacement of oil, not of other forms of energy. Oil is both the main problem and the most readily substituted energy form.

Second, when considering energy conservation priorities, think about the costs associated with the proposed changes in our energy system.

It makes sense to me to tackle the lowest-cost options first. We need to concentrate on applying the most cost-effective conservation and substitution options, rather than, as now, following a policy guided by the mistaken idea that some forms of energy, such as solar energy, are inherently superior to others.

I believe that these two guidelines, concentrating entirely on reduction of oil use and concentrating first on options that are the most cost-effective, will go far toward creating a credible national policy for conservation and energy substitution. But how can we get such a policy implemented?

In many recent studies, estimates are given of the total cost to the nation of imported oil, including costs related to reduced GNP and increased inflation and costs resulting from supply vulnerability. These estimates vary widely, but $70 a barrel seems a credible figure. Some of our concerns about energy conservation and efficiency and fuel substitution could be solved if we could make consumers appreciate that oil really costs the nation two or more times the price that we are paying for it. One way to do this is by removing any barriers to expansion of domestically produced coal, electricity from nuclear plants, and natural gas and by encouraging their increased use as substitutions for the reduced supplies of imported oil.

This sort of approach, I believe, will be much more effective than our present muddle of legislation, regulations, R&D programs, subsidies, and so on. It would especially be more effective than some of the present so-called conservation initiatives that are really subsidies to special interests, for example, small-farm subsidies via the gasohol program. It would promote substantial and rapid conservation of oil. It is time that we in the United States stopped congratulating ourselves about the energy conservation we have achieved and got down to the job of really conserving and substituting for a substantial amount of oil. ■

This article was adapted by Jenny Hopkinson from a speech by Arthur M. Bueche to EPRI's Advisory Council at its Summer Seminar, Aspen, Colorado, on August 13, 1980. Bueche is senior vice president for corporate technology at General Electric Co.

ENERGY FROM BIOMASS

Several offices within DOE are promoting the development of biomass resources. This month's report looks at DOE's near-term programs in wood, agricultural waste, municipal solid waste, and alcohol fuels. A future Washington Report will examine DOE's long-term programs, including bioengineering and energy farms.

Commitment of the federal government to reducing the nation's dependence on imported oil and natural gas is evidenced by the Energy Security Act of 1980. Title II of this legislation, the Biomass Energy and Alcohol Fuels Act, authorizes DOE to finance projects on energy from biomass, municipal wastes, and alcohol fuels.

Within DOE, the Biomass Energy Systems Division is concerned with all forms of energy from biomass except the conversion of sugar, starch, and cellulosic materials into alcohols (under the Office of Alcohol Fuels) and the recovery of energy from municipal solid wastes (under the Office of Energy from Municipal Waste).

All organic matter, whether tiny freshwater algae or giant redwood trees, animal dung or municipal refuse, has energy trapped in its cells. For example, plants capture light and, through the process of photosynthesis, use it to convert water and carbon dioxide into oxygen and energy-rich carbohydrates. When plants or products made from plants burn or decay, this stored chemical energy is released. In the context of energy potential, plants and organic wastes are called biomass.

The energy contained in organic materials is released by both thermochemical and biological processes. Direct combustion is the oldest and most efficient thermochemical process, but gasification and pyrolysis are also effective. The gasification process involves heating the biomass in controlled amounts of air or oxygen, which produces hydrogen and carbon monoxide that can be processed to yield gaseous or liquid fuels. Pyrolysis also uses heat, but without oxygen and at lower temperatures than in the gasification process.

Biological conversion involves the use of enzymes, fungi, or microorganisms to convert biomass into gaseous or liquid fuels. Anaerobic digestion and fermentation are two of the processes; the former produces methane and the latter, ethanol.

Near-Term Applications

DOE's programs on biomass as an energy source are divided into the near-, mid-, and long-term potentials of this diverse technology. Near-term applications include residential, commercial, and industrial uses of wood, energy obtained from agricultural wastes and residues, municipal waste, and alcohol fuels. The mid-term development emphasizes the conversion of matter into low- and medium-Btu gas and anaerobic digestion for producing methane. The more exotic schemes are in the longer-term development projects, which include bioengineering techniques to grow plants with a high-Btu value, studying the feasibility of aquatic farms for producing giant kelp and algae, and establishing energy farms of trees or other high-hydrocarbon plants.

The most promising near-term biomass source is wood, according to Beverly Berger, director of the Biomass Energy Systems Division. DOE estimates that approximately 1.5 quadrillion (10^{15}) Btu (2%) of the nation's energy needs are being supplied by wood and wood waste. The forest products industry uses its own waste materials and is almost 50% energy self-sufficient; this could increase to 80–100% by 2000. In the residential sector, over 8 million homes are presently using wood for space-heating needs.

DOE is currently funding a wood energy demonstration project in Georgia, where three industrial plants will be involved in a cost-sharing project to install wood-fired boilers. DOE has also conducted nine feasibility studies in the textile industry for adapting boilers so they can burn wood to produce process steam. The abundance of wood and wood waste in Georgia and northern Florida make them desirable and relatively inexpensive as fuel for local industries.

The use of wood gasification is being explored in a project with the municipal utility in Starke, Florida. DOE is helping to convert one of the utility's diesel engines to run on wood gas instead of diesel fuel or natural gas.

Residues from lumbering and agricultural activities are another source of energy from biomass. Noncommercial timber, slash material left in the forest after the cutting of trees, straw from rice and grains, and cornstalks can be collected and converted into usable energy. Although large quantities are available, their eventual contribution will depend mainly on the cost of collecting and converting these materials into a fuel that can be used in conventional combustion systems.

The Hawaii Electric Co. in Hilo uses sugarcane waste (bagasse) to generate electricity. This past year the utility generated 34% of its electricity with bagasse as the fuel. Hawaii Electric buys the agricultural waste from local sugarcane mills, which use bagasse to supply almost all their own electricity. In fact, the mills often generate excess electricity and sell it to the utility.

Berger

A municipal utility in Burlington, Vermont, has been using wood chips and waste wood from forest residue since 1977 to fire a 20-MW power plant originally designed to burn coal. The plant burns 1000 tons a week of waste wood and wood chips. At $1–$2 per million Btu, the waste wood and wood chips are cheaper than coal at $4–$8 per million Btu, in spite of the lower heat content of the wood. The success of this plant in Burlington has prompted the Burlington City Council to consider building a 50-MW wood-burning plant in the near future. The Eugene (Oregon) Water and Electric Board burns around 275,000 tons of wood waste annually to produce electricity and steam heat for its service area. (The steam-electric plant first began burning wood waste in 1940.) This utility is also considering municipal waste for electricity generation.

There is a danger that widespread use of wood as a fuel may damage the nation's forests if good forest management techniques are not used. But as Berger points out, the increased demand for wood may force us to better manage our land and forests. "The irony to the aspect of deforestation is that as we use more wood, better forest management techniques are being developed and implemented, so rather than deforestation we will probably have better-managed land. And better-managed land means a closed cycle of carbon dioxide. As trees are cut down, more are planted and grow by using the carbon dioxide in the atmosphere. I guess what I like about agricultural systems or forestry systems is that we are familiar with them, and if we expand their use, the likelihood of detrimental effects may well be less than in some new area where we have little knowledge."

Liquid Fuels

Another near-term application of biomass is the production of alcohol fuels by using well-established conversion processes. According to a recent report by the Office of Technology Assessment, the total U.S. capacity to distill grain into ethanol may reach 0.2 quadrillion (10^{15}) Btu a year by 2000, which is approximately 2 billion (10^{9}) gallons of ethanol a year. Methanol is produced from wood and, like ethanol, can be blended with gasoline to boost the octane value, although it contains 25% less energy per gallon than ethanol.

DOE's Office of Alcohol Fuels is responsible for providing loan guarantees for projects involving the conversion of biological matter into liquid fuels. The office also funds feasibility studies to determine the value of new techniques. DOE is presently sponsoring a project at the

Georgia Institute of Technology in which alcohol fuels are being processed from charcoal for burning in industrial boilers. The results of the project should soon be available for commercial application.

But there are some problems, too. The ongoing debate of food production versus fuel production is one aspect of the economic and social problems associated with the increased use of agricultural matter for energy. If corn and grain are in demand as sources of ethanol to make gasohol, for example, then the lack of these foods as animal feed may increase the price of meat and other foods. The increased price of food falls the hardest on the poor and may well reduce their purchasing power for other goods. An increased use of gasohol will also exacerbate the conflict over land use for food and for energy production. Growing crops for fuel will also compete with U.S. food and feed exports and hurt those foreign nations that rely on American supplies.

As Berger notes, the food versus fuel issue is highly emotional and the answers are not easy. "We can avoid the issue, however, if we increase yields sufficiently and become more efficient in our use of agricultural materials for energy. The forest products industry is a good example. They are getting so they can take any part of a tree and make it useful—nothing goes to waste."

Energy From Garbage

Municipal wastes are the largest single source of biomass now available. As much as 80% of municipal waste is organic; the other 20% consists of metals, glass, and plastics that can be recycled. DOE's Office of Energy from Municipal Waste estimates that by 1990 the energy potential of recovered municipal waste could equal about 2.1 quadrillion (10^{15}) Btu.

Using municipal waste as an energy source would also help solve the environmental problems that such waste now presents. Although some municipal waste is incinerated, most is dumped as landfill, where it can cause chemical runoff, odor, and air pollution. Further, the areas available for landfills are decreasing as the amount of municipal waste is continuing to increase.

Bechtel Corp. estimated that the amount of municipal wastes produced in the United States in 1975 could provide fuel to generate 6–7% of urban electricity demand. The cost of converting these wastes into a usable energy form is high, however, because of the pretreatment process. After separating the organic wastes from the inorganic, the remaining material must be shredded and sent through an air classifier to yield a fuel source. It is projected, however, that the sale of the recovered metal and glass could partially cover the cost of the pretreatment process. Municipal liquid waste (sewage) is also being processed through anaerobic digestion to make methane gas, but not on a large scale. The methane produced is often used by the sewage treatment plants to meet some of their heating and electricity needs.

In Pompano Beach, Florida, DOE is sponsoring a project to convert waste materials to energy at Waste Management, Inc., which is the first privately owned and operated facility of this type. Between 50 and 100 tons of municipal waste are processed at the plant each day and are converted into methane and carbon dioxide. After the pretreatment processes, the waste materials are placed in a tank with sewage sludge, water, and nutrients. This mixture is then fed into anaerobic digesters, where it is converted biologically into half methane and half carbon dioxide. DOE will perform a feasibility study on the process to assess if it can be used commercially. Waste Management expects to produce enough methane to serve the energy requirements of about 10,000 families.

Nearly $1 million will be provided by DOE to New York City to continue the development of a plant that will generate steam by burning municipal waste. Located in the Brooklyn Navy Yard, the plant is expected to burn approximately 3000 tons of refuse each day to generate steam for sale to Consolidated Edison Co. of New York, Inc. It is estimated that the plant's annual steam production will be equivalent to that produced by burning 1 million barrels of oil in a conventional oil-burning plant. DOE will cofund the project with New York City through the start of construction in the fall of 1981.

Progress by 2000

The near-term applications of biomass energy are already meeting some of the nation's energy needs, and aided by the technical and financial incentive programs of DOE, they will continue to help meet the energy demand. "For the near-term applications we are very concerned about the end use, and we try to help speed things up. In the long term, however, the end-use applications are not the most difficult questions. Our research is concerned with increasing the yield per acre and in improving the conversion technologies. But there are always trade-offs, and we have to learn to invest the federal dollar to get the best returns. I would also say that with reasonable R&D success, biomass could contribute about 10 quadrillion (10^{15}) Btu to our energy requirements in the year 2000," comments Berger. This projection is not unreasonable, as she points out: "Biomass is clearly the only solar technology that is contributing significantly today. In 1979 its contribution was approximately 1.5 quadrillion Btu, even by the most conservative estimates. And I think it will be the largest contributor of the solar technologies in 2000."

In a future Washington Report, the scope of DOE's long-term biomass programs will be discussed. ■

Four European Utilities Join NSAC

The information network of the Nuclear Safety Analysis Center is being extended internationally. Computer access to all sponsoring utilities is one vital function.

Electricité de France (EDF) became the first international sponsor of the Nuclear Safety Analysis Center (NSAC) on November 3, 1980. Three Swedish electric utilities announced their support of NSAC on November 14, 1980: Vattenfallsverk (the Swedish State Power Board), Sydkraft Ab (Southern Swedish Power Supply Company), and Oskarshamnsverkets Kraftgrupp Ab (Oskarshamn Power Group). The three utilities own Sweden's seven operating nuclear plants.

NSAC, which is operated by EPRI for the U.S. electric power industry, was established after the Three Mile Island accident to make a thorough investigation and provide a detailed analysis of what happened. It is also responsible for studies on generic nuclear safety questions and recommending actions to prevent future nuclear accidents.

Under the sponsorship agreement, the four European utilities will have access to the studies prepared by NSAC and the documents it collects on nuclear safety. They will also have access to NSAC's computer data base and teleconferencing system, which is now used by all U.S. utilities that operate nuclear power plants.

"This system will now be extended internationally and will help make nuclear power safer everywhere," commented NSAC Director E. L. Zebroski. The system permits any member to contact all other members via a remote computer terminal used with an ordinary telephone connection, thereby permitting the entire industry to share relevant safety information and experience at electronic speed.

France has the most vigorous and ambitious nuclear power program in the world today. About 10 years ago the French government decided not to build new coal- or oil-fired power plants. Of the 20 nuclear power plants operated by EDF, 12 are PWRs based on the Westinghouse Electric Corp. design. In addition, EDF has 37 PWRs under construction. ■

Levenson Joins Bechtel

Milton Levenson, director of the Nuclear Power Division since 1973, will leave EPRI in January to join Bechtel Power

Corp.'s San Francisco Power Division as an engineering consultant. At Bechtel he will be involved in special studies regarding the design of power plants.

Before joining EPRI, Levenson was associate laboratory director for energy and environment at the Argonne National Laboratory. He served as the chairman of Argonne's Reactor Safety Review Committee from 1954 to 1968 and as a technical adviser at the Geneva Conference on the Peaceful Uses of Atomic Energy in 1958, 1964, 1971, and 1975. From 1944 until he joined Argonne in 1948, Levenson worked at what is now the Oak Ridge National Laboratory.

Levenson is a chemical engineering graduate of the University of Minnesota. He is a member of the National Academy of Engineering, a fellow of the American Nuclear Society, and a member of the American Institute of Chemical Engineers, whose Robert E. Wilson award he received in 1975. ■

ET8 Convenes in March

The eighth annual Energy Technology Conference and Exposition (ET8) will be held March 9–11, 1981, in Washington, D.C. EPRI will again cosponsor the event with the American Gas Association, the Gas Research Institute, and the National Coal Association. More than 6000 are expected to attend.

With the theme "New Fuels Era–80s," the conference will include 65 technical sessions and workshops on synthetic fuels, renewable resources, industrial energy management and conservation, alternative transportation fuels and engines, and strategies for the transition from oil to coal. A special session, Energy in a Finite World, will report on the seven-year global energy study that is being conducted by 140 energy specialists.

J. Peter Grace, president and chief executive officer of W. R. Grace and Co., will present the traditional state-of-energy message, and S. David Freeman, chairman of the Tennessee Valley Authority, will give the founders' luncheon address. The conference will close with an energy prospectus delivered by Armand Hammer, chairman and chief executive officer of Occidental Petroleum Corp.

The concurrent ET8 Exposition will display 350 exhibits of energy hardware, research, and services of interest to utility executives, as well as to industry and government representatives, builders, and architects.

EPRI representatives are organizing the following sessions: R. L. Rudman, Reducing Oil Imports; Fritz Kalhammer, Electric Load Management; René Malès, Utility Rate Design; Burton Nelson, Role of Public Utility Commissions in Promoting Application of R&D Results; and Ralph Manfred, Conversion of Oil-Fired Power Plants to Coal. EPRI speakers include John Maulbetsch, Robert Malko, Bert Louks, and Ralph Perhac. Serving on the ET8 Program Committee are R. L. Rudman and Michael Tinkleman; Christine Lawrence is the liaison for publicity.

ET8 is managed by Government Institutes, a private publishing and educational organization. Advance programs, registration materials, and exhibitor information for ET8 are available from Martin Heavner, Government Institutes, P.O. Box 1096, Rockville, Maryland 20850; (301) 251-9250. ■

NDE Conference

EPRI's second annual Nondestructive Evaluation (NDE) Information Meeting was held in Palo Alto, California, on October 22–23. Thirty-one NDE projects currently being funded by EPRI's Nuclear Power Division were presented during the meeting. The 120 attendees represented utilities, service companies, the Nuclear Regulatory Commission, architect-engineers, and R&D organizations. A seven-member delegation from England attended, as well as guests from Belgium, Spain, and West Germany. From left: Gary Dau, NDE program manager at EPRI; Paul Caussin, Belgium; Earnest Shannon, British Gas Corp.; Robert Stone, J. A. Jones Applied Research Co.; Michael Farley, Babcock Power, England; John White, Central Electricity Generating Board, England; Paul Höller, West German NDE Center; Frank Arrotta, assistant director of EPRI's Nuclear Power Division; Graham Oates, Central Electricity Generating Board, England.

Starr Awarded Honorary Degree

Chauncey Starr (front row, second from right), director of EPRI's Energy Study Center and vice chairman of EPRI, was awarded an honorary degree by the Eidgenössische Technische Hochshule (ETH) (School of Electrical Engineering, Swiss Federal Institute of Technology) in Zurich on November 28, 1980. The presentation was part of a jubilee week celebrating ETH's 125th anniversary. ETH is among the oldest and most prestigious universities in Europe and a world-renowned technical institute. This degree honors Starr's "outstanding achievements in research and teaching, as well as his leadership in the field of power engineering."

CALENDAR

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

FEBRUARY

22–24
Symposium: Integrated Environmental Controls for Coal-Fired Power Plants
Denver, Colorado
Contact: Dan Giovanni (415) 855-2442

MARCH

25–27
Symposium: Load Forecasting
Kansas City, Missouri
Contact: Robert Crow (415) 941-6637

30–31; April 1
Workshop: Rate Design Study—Costs and Rates
Palo Alto, California
Contact: Nancy Hassig (415) 855-2176

APRIL

8–10
Workshop: Rate Design Study—Costs and Rates
Atlanta, Georgia
Contact: Nancy Hassig (415) 855-2176

22–24
Workshop: Rate Design Study—Costs and Rates
Kansas City, Missouri
Contact: Nancy Hassig (415) 855-2176

SEPTEMBER

15–17
Workshop: Modeling of Cooling-Tower Plumes
Chicago, Illinois
Contact: John Bartz (415) 855-2851

21–25
Workshop: Zero Discharge
Steamboat Springs, Colorado
Contact: Roger Jorden (415) 855-2463
Ronald Kosage (415) 855-2869

OCTOBER

20–22
Workshop: Modeling the Performance of Cooling Towers
Chicago, Illinois
Contact: John Bartz (415) 855-2851

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

FUSION POWER SYSTEMS

The primary objective of EPRI's Fusion Power Systems Program is to ensure the identification, selection, and development of fusion systems that can be used by the electric utility industry. Recent organizational changes at EPRI, as well as an Energy Resource Advisory Board review of the federal fusion program, have prompted a reappraisal of the role and strategy of EPRI's fusion research. This reappraisal has involved the utility advisory committees, an independent review group, and Institute staff at all levels. The resultant program will focus on defining engineering issues crucial to the development of practical, economical, environmentally acceptable fusion power systems that have the reliability, availability, maintainability, and electrical characteristics essential for integration into utility systems. EPRI will closely coordinate its program with DOE, which is beginning the engineering activities necessary to develop fusion systems that can be used in practical applications.

Worldwide effort

In the last 25 years, controlled fusion research has grown from small experimental efforts to a mature worldwide research effort. Currently, some 9000 scientists and engineers in the United States, the Soviet Union, Japan, and Europe are working to demonstrate the scientific feasibility of controlled fusion. Most professionals in the field believe that the milestone of energy break-even (the production of as much energy by a device as is required to produce the fusion reaction) will be reached by 1984 with the successful operation of the tokamak fusion test reactor (TFTR) at Princeton University's Plasma Physics Laboratory in New Jersey.

The fusion program of the federal government, directed by DOE, has a budget of over $500 million in FY81. This effort represents about one-third of the total commitment to fusion worldwide. The EPRI program—although small in comparison, with an average yearly budget of $3 million—has sponsored 41 projects since 1974. These have included investigations of first wall—blanket systems, remote handling, reactor control, preliminary small-system design concepts, low-activation materials, alternative concepts, and advanced-fuel systems.

Research challenges

In the fusion process, energy is released when the nuclei of isotopes of hydrogen or certain other light elements combine. The process and its promise have been understood since the early 1930s. The primary fuel—deuterium, an isotope of hydrogen—is available in water. One 8-oz (236-cm^3) glass of water (even ocean water) contains the fusion energy equivalent of the chemical energy in 300 gal of gasoline. If this fuel could be successfully and economically used, it would supply the world with an essentially unlimited energy resource. However, the peaceful application of nuclear fusion has yet to be demonstrated. The basic conditions required to "burn" fusion fuels are extreme and not easily obtained on the surface of the earth.

There are natural fusion reactors—the sun and other stars. The sun's core temperature is estimated to be 13,000,000 K and its hydrogen fuel is confined by gravity. To accomplish a useful fusion burn safely on the earth's surface requires fuel temperatures of 100,000,000 K and isolation of the fuel from the reactor walls by either strong magnetic fields or high-density fuel compression. Experiments to date have established fuel temperatures, densities, and confinement times near those required for a fusion power plant. Figure 1 shows recent U.S. research progress and the anticipated results of current experiments. Note that the TFTR is expected to achieve energy break-even.

Goals of EPRI program

In the context of the large, rapidly developing international research effort, the EPRI Fusion Power Systems Program is now emphasizing five major objectives.

- Identifying and evaluating technical issues crucial to the engineering development of practical fusion power systems for the utility industry
- Encouraging innovative, utility-oriented approaches to the engineering development of fusion power
- Performing state-of-the-art assessments and communicating them to utilities
- Maintaining close links with DOE and defining appropriate engineering experiments to complement the federal program
- Supporting engineering project activities in areas common to all fusion technologies

The program emphasizes utility-oriented issues, such as power plant size, compatibility with a utility grid, and maintainability. The major thrust of DOE's program has been large (1-GW [e]) fusion power plants. The development of concepts in support of small systems could improve fusion's ultimate penetration capability.

To implement its goals, the EPRI program is organized into three subprograms: magnetic confinement fusion, inertial confinement fusion, and analysis and technical development.

The magnetic confinement fusion subprogram complements the much larger federal program in this area, which is pursuing the goal of scientific feasibility. The EPRI subprogram is performing technical risk assessments of selected engineering activities, identifying and supporting the development of promising magnetic concepts, and providing performance evaluations of magnetic fusion experiments. For example, several small-reactor concepts are being evaluated (RP922). It is hoped that these will lead to systems that can be developed for early utility applications.

Similarly, the inertial confinement fusion subprogram complements a much larger federal program. Present federal efforts are aimed at establishing the scientific credibility of inertial confinement, a goal that requires the construction of large driver systems, an examination of the basic physics of driver-target interactions, and the design of realistic targets.

The major goal of EPRI's subprogram is to define technical and preliminary engineer-

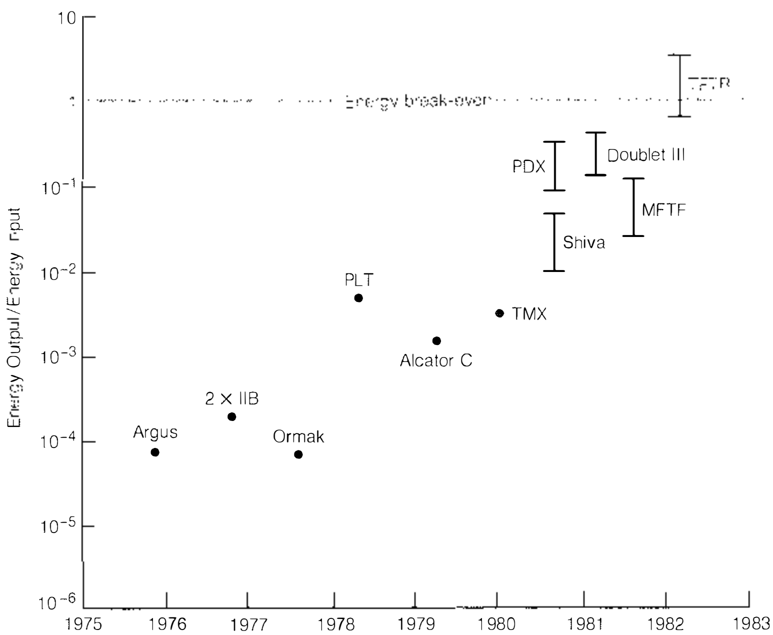


Figure 1 Experimental results (or expected performance ranges) for current U.S. fusion research projects. The vertical scale represents the ratio of fusion energy produced to the energy required to heat the fuel. TFTR is expected to achieve energy break-even.

ing activities that will help determine the potential of inertial confinement fusion for power production. Specific projects involve the identification of utility-preferred systems, assessments of the developing technologies expected to have utility applications, and performance evaluations of existing and planned systems and components. Under RP1346, for example, inertial fusion drivers were assessed. It was concluded that a small inertial system with a light-ion-beam driver may be possible (AP-1371), and a project to develop a conceptual design for such a system is being planned (RP1527).

The analysis and technical development subprogram emphasizes activities relevant to both magnetic confinement and inertial confinement fusion. Like the other two subprograms, it evaluates new technical approaches, conducts technical risk assessments in selected areas (one important example is fusion-fission hybrids), and develops state-of-the-art information for utilities. It is also planning to conduct engineering experiments at existing fusion facilities—for example, blanket engineering tests on the TFTR. By comparing alternative engineering development paths, this subprogram seeks to determine the most effective route to useful fusion power.

Technical risk assessments

A major part of the fusion program is expected to involve technical risk assessments of near-term engineering systems. The following general tasks are involved.

- Define the objective of the system
- Identify the system and its components
- Complete the specific design of selected systems
- Conduct operational and systems analysis for each system
- Identify key scientific, technical, and engineering risks
- Define the data base for relevant scientific, technical, and engineering issues
- Develop and apply methodology for optimizing the system to meet the objective
- Compile a detailed plan for reaching the objective

Although fusion subsystems are not yet sufficiently defined to permit detailed failure risk analyses, the general engineering approach represented by these tasks can be used to identify technological deficiencies that must be eliminated. A completed analysis should provide plans for correcting any deficiencies found.

EPRI also expects to cooperate with the much larger federal program in such engineering experiments as the fusion blanket engineering tests described in the next article. *Program Manager: F. R. Scott*

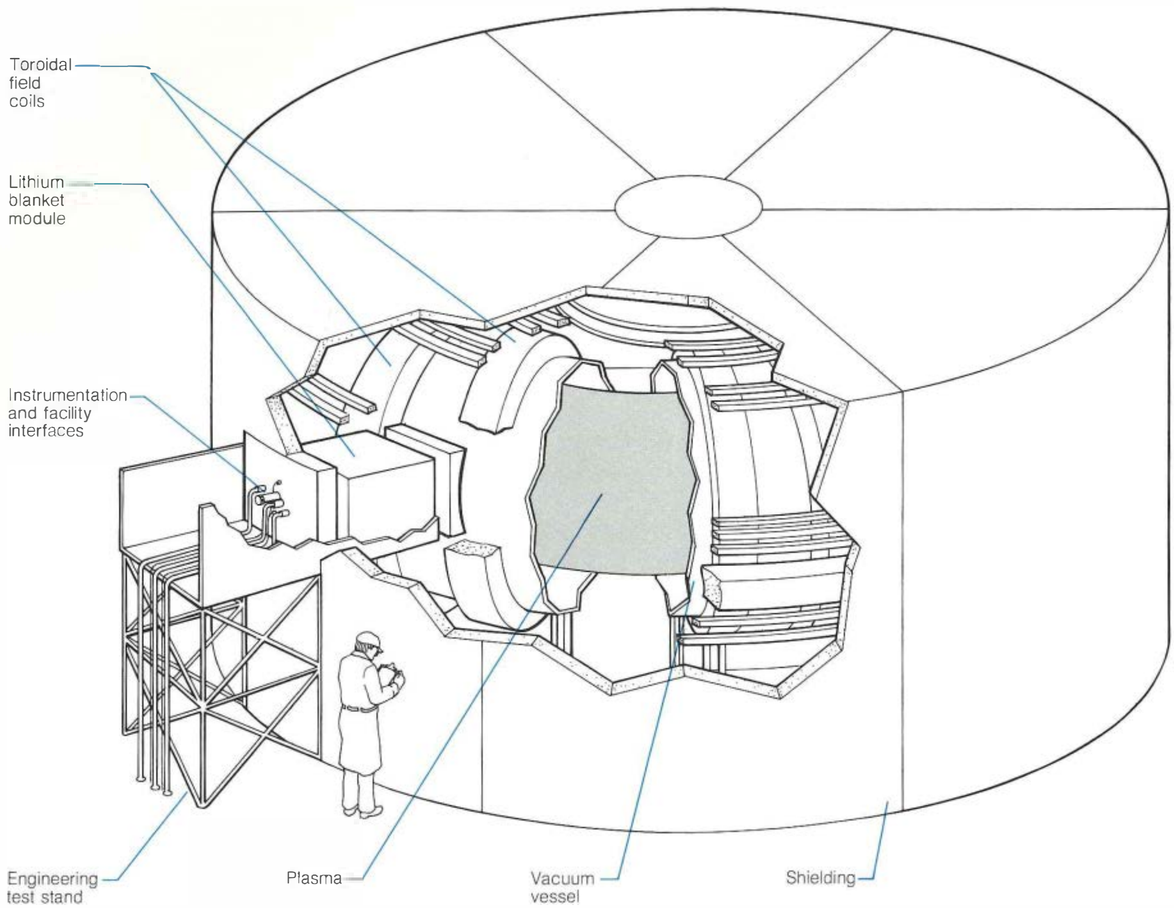
FUSION BLANKET ENGINEERING TESTS

Converting the energy produced by deuterium-tritium (D–T) fusion for electricity generation or other practical applications requires that the reacting plasma be surrounded by a blanket. Neutrons released in the fusion reactions enter this blanket, where their kinetic energy is transformed into heat. Also, one component of the fusion fuel, tritium, must be produced in the blanket through the capture of neutrons by lithium. To date, most experimental work in controlled fusion has been concerned with producing the reacting plasma. However, because of the significant advances that have been made in plasma confinement and heating, the emphasis of fusion R&D is shifting to the solution of engineering problems, including the optimal means of using the fusion neutrons in the blanket region. Operation of the TFTR at Princeton, scheduled to begin in 1982, will offer one of the first opportunities for large-scale blanket module experiments. In cooperation with DOE, EPRI is planning to conduct a blanket engineering test program at that facility (RP1748).

The TFTR will use D–T fuel and will be capable of generating several tens of megawatts of fusion power. Most of that power (80%) will be in the form of high-energy (14-MeV) neutrons. The device (Figure 2) will have a geometrically extended D–T fusion neutron source and a neutron spectrum (including backscattered neutrons) like that expected in a practical toroidal fusion reactor. Deuterium-only operation, producing 2.45-MeV neutrons, is expected to begin in late 1982. D–T operation, producing 14-MeV neutrons, is expected to begin in 1984.

EPRI has initiated a project to define fusion blanket engineering tests using the TFTR's toroidal fusion neutron source (RP1748). The general objectives of this effort are to conduct a series of neutron transport and tritium-breeding experiments with a lithium blanket module (LBM) and to compare the data obtained with predictions of reactor blanket design codes. The LBM

Figure 2 Cutaway view of Princeton University's tokamak fusion test reactor, which will be used in EPRI's blanket engineering test program. The lithium blanket module will be supported by an engineering test stand for conducting neutron transport and tritium-breeding experiments.



research will also determine how the design codes and neutronics data should be improved in order to bring calculations of performance into closer agreement with experimental results.

This program of experimentation and analysis, the first of its kind using a controlled fusion device, has the potential to significantly increase confidence in fusion reactor blanket design concepts and to demonstrate the feasibility of closing the D–T fuel cycle. It is also expected to provide reactor-prototypic experience in several key areas, including fabrication of tritium-breeding elements, blanket instrumentation, remote handling of blanket modules, electromagnetic isolation of blanket modules from the tokamak plasma, and safe integration of a blanket module into a D–T tokamak reactor assembly.

The test module will be held in position next to the TFTR vacuum vessel by an engineering test stand (ETS), also shown in Figure 2. It will be located in one bay of the TFTR, between adjacent toroidal field coils. The ETS will be able to support blanket modules up to about 78 cm in width, 84 cm in height, and 100 cm in depth, and weighing up to 4 Mg.

Princeton's Plasma Physics Laboratory, the TFTR site, is designing the ETS and coordinating project activities with the TFTR. General Atomic Co. has been selected as the contractor for the LBM tasks, including design, fabrication, experimentation, and analysis. Module design and the definition of a series of experiments are under way, with a major technical review of the project scheduled for mid-1981. If the evaluation is favorable, ETS and module construction will be initiated in 1981 and the module scheduled for delivery in 1983. After installation and acceptance testing, experimentation could begin in 1983 and run to mid-1985.

A key element in the viability of the LBM research is that it will not have adverse effects on the operation of the TFTR device, whose principal mission is to investigate reacting D–T plasmas; therefore, neither the ETS nor the module will be attached to any component of the TFTR. Preliminary work (TPS79-705) indicated that the electromagnetic interaction of the module and the ETS with the plasma can be made insignificant. Furthermore, LBM activities will require only infrequent removal of the module, which can be accomplished by TFTR remote maintenance equipment during scheduled TFTR downtime. *Project Manager: N. A. Amherd*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

NO_x CONTROL TECHNOLOGY

The availability of technology for controlling emissions of nitrogen oxides (NO_x) is becoming a major issue in the expansion of conventional coal-fired power generation. The maximum NO_x emission levels presently allowed by federal New Source Performance Standards (NSPS)—0.5 lb/10^6 Btu for subbituminous coal (375 ppm) and 0.6 lb/10^6 Btu for bituminous coal (450 ppm)—are verging on the limits of NO_x control available through conventional technologies. However, pressure continues from environmental and regulatory sectors for further significant reductions in NO_x emissions. For example, EPA has published a near-term NO_x emission goal of 0.2 lb/10^6 Btu (150 ppm), corresponding to a control level of 80–85%. Even more stringent local regulations have been established in several areas. The EPA requirements are being governed by the visibility, oxidant, and ambient NO_2 standards emerging from the Clean Air Act Amendments of 1977. The possibility that NO_x contributes to acid rain has created additional urgency. These factors and the uncertain future availability of reliable, cost-effective NO_x controls for pulverized-coal-fired power plants constitute the rationale for EPRI's NO_x control R&D effort within the Air Quality Control Program.

Modifications in the boiler combustion process are the only commercially available means of controlling NO_x emissions from coal-fired power plants. This approach, which usually involves some form of staged combustion or low-NO_x burners, attempts to minimize NO_x formation by limiting the amount of oxygen available for chemical combination with nitrogen from the air and the fuel. Such methods were generally sufficient to meet the NSPS imposed in 1971, which limited NO_x emissions from coal-fired plants to 0.7 lb/10^6 Btu. It is generally believed that these controls can be refined to meet the present federal NO_x regulations (i.e., 0.5 and 0.6 lb/10^6 Btu). In fact, such levels have already been demonstrated at a number of utility plants, and the operational and maintenance problems appear to be surmountable. Although the significantly stricter NO_x emission limits anticipated for the mid-1980s are well beyond the capability of any commercially available control technology, the successful development of advanced combustion modifications capable of reducing NO_x emissions to approximately 0.2 lb/10^6 Btu now appears certain. These new systems are expected to be commercially available in three to five years at an estimated additional cost of \$5–\$10/kW.

In addition to the combustion control approach, regulatory agencies have become increasingly interested in postcombustion flue gas treatment to control NO_x emissions. Flue gas treatment for NO_x removal, pioneered in Japan, is a recent development. Of the over 50 processes that have been identified, the selective catalytic reduction process appears to be the most likely candidate for utility consideration. In this process ammonia is injected into the flue gas duct in front of a large catalytic reactor. Within the reactor, the ammonia reduces NO_x to molecular nitrogen (N_2) and water. In principle, this approach could reduce NO_x emissions to 0.1 lb/10^6 Btu or below. However, the applicability of this process to coal-fired power plants is uncertain. There are many unresolved questions about long-term performance, process control, by-product emissions, and adverse interaction with downstream boiler and emission control equipment. The estimated cost of such a system is \$100/kW (approximately 10 times that of combustion control), with annual operating costs as high as \$25/kW, depending on the frequency of catalyst replacement.

The emphasis of EPRI research has been on the combustion control method, and projects are under way with major boiler manufacturers to develop low-NO_x combustion processes. In response to increased regulatory interest in the flue gas treatment approach, EPRI is also supporting projects to clarify the cost and potential operating and environmental problems associated with using selective catalytic reduction in a coal-fired plant.

Low-NO_x combustion process development

Conventional combustion controls are effective in minimizing the formation of NO_x from atmospheric nitrogen in the combustion air, but they are not effective in controlling NO_x formation from nitrogen bound in the coal (typically 1–2% by weight). However, there is now a considerable amount of fundamental data indicating that even the fuel-bound nitrogen may be reduced to harmless molecular nitrogen by careful manipulation of the combustion chemistry. This is the focus of advanced combustion control development.

Virtually all advanced low-NO_x combustion processes under development involve the concept of staged combustion. While there may be some similarities between these processes and the conventional staged combustion now found in the industry (e.g., the use of overfire air ports), the advanced processes represent a major step forward. They have much greater sophistication in the control of fuel-air mixing and introduce substantially different combustion chemistries.

There are numerous approaches to providing favorable low-NO_x conditions during coal combustion in terms of furnace geometry and other design variables, but two essential requirements have been identified: The coal is partially burned under oxygen-deficient (reducing) conditions to release a portion of its heat energy. Then the products of this incomplete combustion are mixed with enough air to complete the combustion process and release the remainder of the heat energy. The actual combustion process chemistry is far more complex than this simplistic explanation implies.

Two EPRI efforts involve the modification of furnace geometry to control NO_x formation: the primary combustion furnace (PCF) being developed by Babcock & Wilcox Co. (B&W) under RP899 and the arch-fired furnace being evaluated by KVB, Inc., and Foster Wheeler Energy Corp. under RP1339. In the PCF, which represents a unique extension of conventional staged combustion, coal is burned in two distinct chambers (Figure 1). In the first chamber, coal is introduced into conventional B&W dual-register burners with less air than is required to complete the combustion. The coal partially burns to permit the desirable N_2-producing reactions to occur. Secondary air is added at the entrance to the second chamber to bring the combustion products to oxidizing conditions for passage through a conventional convective section. As envisioned for utility application, this two-stage process is incorporated into a venturi furnace design.

Process development of the PCF was carried out at scales of 4×10^6 Btu/h and 35×10^6 Btu/h. These tests have defined the process variables necessary to accommodate low NO_x formation while maintaining acceptable combustion characteristics. Results show that under optimal conditions, NO_x emission levels of 0.2 lb/10^6 Btu can be achieved for representative utility coals ranging from lignite to bituminous coal. Furthermore, B&W has predicted that similar NO_x levels can be maintained in a full-scale venturi furnace. It has been concluded that there are no major engineering barriers to the commercialization of the venturi furnace, but furnace wall corrosion in the PCF and control of second-stage air mixing are matters of concern. B&W has proposed follow-on efforts to address these issues. The cost estimate provided by B&W for this technology represents a \$6/kW differential cost increase over conventional boilers.

In contrast to the PCF, the Foster Wheeler arch-fired furnace accomplishes low NO_x formation in a single furnace volume (Figure 2). Coal is fired downward from an intermediate roof (arch) in the furnace and burns in stages as the combustion air is introduced sequentially through slots along the side wall. Arch firing is currently being used by Wisconsin Electric Power Co. in older boilers ranging in size from 80 to 275 MW. Although these boilers were not originally designed for the purpose of NO_x control, their low-NO_x characteristics result from their inherent combustion staging. Field tests by KVB, Inc., indicate that NO_x emissions from the arch-fired furnaces are almost as low as those achieved in the B&W PCF. Furthermore, the furnaces have demonstrated an availability record comparable to Wisconsin Electric's conventional boiler designs. Foster Wheeler is completing a feasibility study to evaluate the engineering and economic implications of applying arch firing to modern utility boiler designs and sizes.

Both the PCF and the arch-fired furnace are primarily aimed at new plant designs.

Figure 1 Babcock & Wilcox's two-stage venturi furnace physically isolates the primary (reducing) furnace from the secondary (oxidizing) furnace, providing controlled combustion staging for reduced NO_x formation.

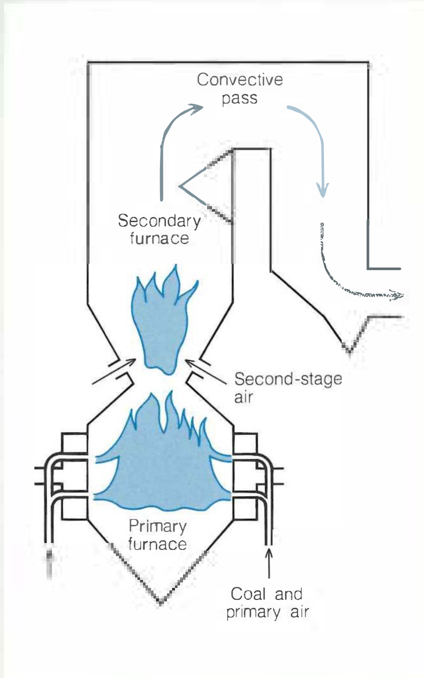
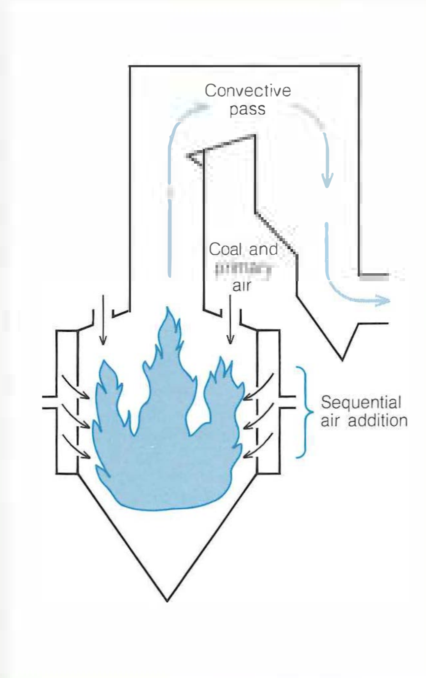


Figure 2 In Foster Wheeler's arch-fired furnace, coal is injected downward from furnace arches. NO_x formation is reduced because the coal burns slowly, with combustion air added in stages from the side walls.



In response to increasing pressure to reduce NO_x emissions at existing sources, the EPRI program is being expanded to include the evaluation of low-NO_x burners that can be retrofitted. One such effort (RP1836), jointly funded with the Electric Power Development Co. of Japan, will involve Combustion Engineering, Inc., and Mitsubishi Heavy Industries. This work, scheduled for completion during the first quarter of 1981, will confirm the low NO_x performance of a new burner that can be retrofitted for use with tangentially fired boilers. Performance tests using U.S. utility coals will be conducted on a test furnace in Japan at a scale of 80×10^6 Btu/h. This work will be complemented by an engineering feasibility study of retrofit and new unit applications by Combustion Engineering.

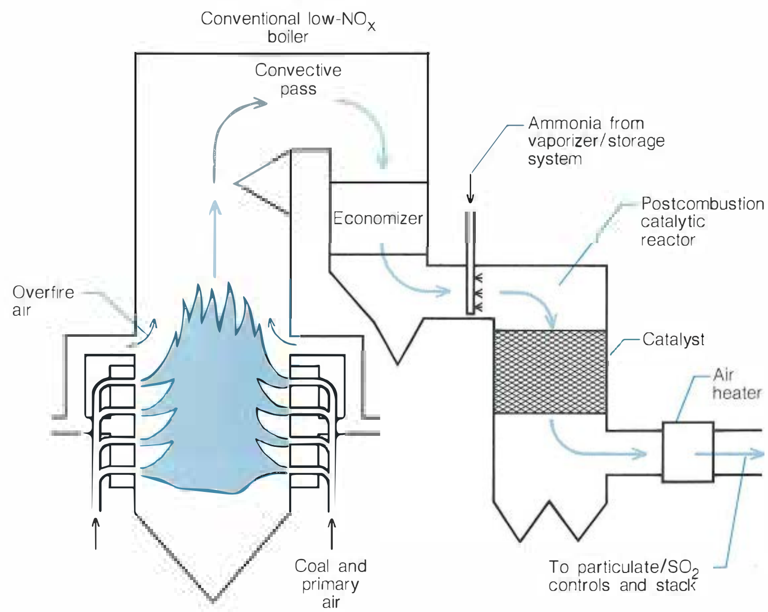
Postcombustion NO_x control

While the major emphasis of NO_x control at EPRI is on the cost-effective combustion control approach, considerable research is being conducted on the postcombustion alternative. EPA is evaluating the potential for simultaneous dry NO_x and SO_x control with UOP, Inc. In another EPA study with Hitachi-Zosen, catalytic NO_x control will be investigated. Both projects are being run at a 0.5-MW pilot plant scale.

EPRI's research goal in this area is to determine the cost, operational, and reliability effects of an ammonia-based catalytic NO_x control system in a coal-fired power plant (Figure 3). This effort is centered at a 2.5-MW catalytic NO_x pilot plant at EPRI's Emissions Control and Test Facility in Denver, Colorado (RP1256). Using flue gas from Public Service Co. of Colorado's Arapahoe power station, the pilot plant will permit identification and evaluation of key factors involved in integrating such a process into an operating power plant. Factors to be addressed include startup and shutdown requirements, load following, ammonia carryover, catalyst plugging, catalyst erosion, and undesirable by-product emissions. Ammonia carryover poses some especially difficult operating problems because it can lead to air preheater deposition and corrosion, blinding of baghouses, ammonia and sulfate emissions, and formation of visible plumes.

The pilot plant now contains a three-stage catalyst element (supplied by Kawasaki Heavy Industries), which is followed by a Ljungstrom air preheater. Future plans call for the addition of particulate and SO_2 control devices to evaluate how they are affected by ammonia and by-product emissions. Adverse effects on these devices

Figure 3 Conceptual design for an ammonia-based system for postcombustion catalytic NO_x control. The system would use a conventional low-NO_x pulverized-coal boiler with a catalytic reactor added for flue gas treatment.



or the air preheater may significantly increase the cost of applying postcombustion NO_x controls.

In addition to the pilot work, feasibility studies by architect-engineers are addressing the practical engineering aspects of postcombustion NO_x controls. The feasibility of retrofitting catalytic controls was evaluated for a 100-MW coal boiler (RP982), which may be the first logical scale-up size before commercial-scale commitment to this technology can be confidently considered. In another project (RP783), cofunded with EPA, the installation of postcombustion controls on new units has been considered.

Appraising alternatives

EPRI's NO_x research has a dual purpose: to support the development of alternative low-NO_x combustion systems and to prevent the premature or unwarranted commercialization of postcombustion NO_x control processes. The approach involves cooperative R&D efforts with major U.S. and Japanese manufacturers and utility companies. If boilers with NO_x emissions at or below 0.2 lb/10^6 Btu were available, it is unlikely that costly postcombustion processes could be justified. To effectively address the regulatory and technical issues associated with postcombustion controls, it is imperative that the utility industry be knowledgeable about the true cost and development status of these processes. Specifically, an understanding of the cost and risk associated with an incremental reduction in NO_x emissions by postcombustion control (compared with new low-NO_x combustion systems) is essential. EPRI's postcombustion NO_x pilot plant and engineering studies are providing the industry with the most credible, thorough information available. *Project Managers: Michael W. McElroy and J. Edward Cichanowicz*

HIGH-INTENSITY IONIZER

The need for an efficient precharging device to improve electrostatic precipitator (ESP) performance provided the impetus for research on the high-intensity ionizer (HII). Specifically, utilities required a simple, low-cost means of upgrading ESPs that were not in compliance with particulate matter emission regulations. Initially promising laboratory results and encouraging pilot work conducted on an HII at TVA's John Sevier steam plant prompted EPRI to initiate a research program in 1975 to respond to this need.

Early research

The initial research approach involved evaluation of the charging capabilities of a prototype HII under controlled operating conditions and at a scale representative of utility ESP installations; the research goal was to provide the basic data necessary to formulate HII design and operating guidelines for commercial applications. This evaluation, principally EPRI-funded, was performed in 1978 on a 10-MW prototype ESP at EPRI's Advanced Emissions Control and Test Facility at the Arapahoe station of Public Service Co. of Colorado.

The HII–ESP combination must achieve three technical goals to be considered successful: The HII must impart an enhanced charge to the fly ash particles; the particles must retain this high charge as they pass through the HII assembly and transition cavity into the ESP; and the ESP must respond by efficiently collecting these highly charged particles without deterioration of performance over time. Unfortunately, the HII tested at Arapahoe in 1978 did not achieve these goals. Collection efficiency of the Arapahoe 10-MW ESP did not improve enough to warrant further engineering development and scale-up. The performance enhancement occasionally observed in the earlier TVA studies could not be routinely duplicated.

Although some process modifications were attempted to improve HII performance, the results were inconclusive. The research effort was then redirected toward identifying HII performance limitations. A hardware development project was begun in April 1979.

Current research

The redirected project objectives were to identify the factors that limited performance and to develop hardware and process improvements that would overcome these limitations. HII particle-charging capability was shown to be limited by back-ionization associated with the accumulation of fly ash on the anode vanes in the HII throat. This limitation was alleviated by redesign of the anode purge gas system: The temperature was reduced to 100°F (38°C); the purge gas flow rate was increased to 8% or more of the flue gas flow rate; and the moisture content was raised to 6% by volume.

Particle-charging capability was also found to be limited by a loss of charge within the HII diffuser cone, caused by electrical arcing at the HII outlet. This limitation was overcome by changing the geometry of the HII to eliminate the diffuser cone on the discharge side. The new design, called double bellmouth, has symmetric inlet and outlet geometries.

Combination of the improved anode purge gas system and the double bellmouth geometry produced favorable results. In the laboratory, both the charge-to-mass and charge-to-volume ratios increased continuously with ionizer electrical field strengths up to 10 kV/cm. This indicated that HII charging capability was improved significantly by the new design. This enhanced charging capability was verified through tests on the 1-MW ESP at EPRI's Arapahoe test facility.

As a result of these efforts, the new HII configuration has been shown conclusively to impart an acceptable charge on the particles, and this charge is retained as the particles pass through the HII assembly. What remains to be determined is whether the charge can be maintained until the particles enter the ESP and under what conditions and to what degree ESP performance is improved by the HII. Current work to resolve these issues is directed at the HII–ESP coupling. The work is being conducted with the 1-MW ESP at Arapahoe and the HII/wire-tube ESP at Air Pollution Systems, Inc. (APS) laboratories.

Preliminary results of these two parallel efforts have provided valuable insights. The Arapahoe studies have shown that flue gas velocity profiles downstream of the double-bellmouth HII depend on the flue gas flow rate and the ratio of the purge gas and flue gas flow rates. A uniform velocity profile is essential for satisfactory ESP performance. The profile is reasonably uniform downstream of the HII when the purge gas flow rate is about 16% of the flue gas flow rate; however, the purge gas reduces ESP effectiveness by decreasing the anode plate area per volume gas flow, or specific collection area (SCA), by an equivalent 16%.

The APS studies have indicated that some of the charge imparted by the HII may be lost within the transition plenum (cavity) between the HII and the ESP. The charge loss appears to be more severe for higher mass loadings. In addition, operation of the ESP in back-ionization must be avoided, because particle charge neutralization will occur and substantially negate the beneficial effects of charge imparted by the HII.

Unresolved technical issues

Since the hardware development program began in April 1979, technical progress has been significant. However, before the HII can be implemented commercially, several key issues need to be resolved.

The incremental benefits to be derived when the HII is applied to an ESP operating in back-ionization are uncertain. There are different types of back-ionization—for example, streamer back-ionization, in which electric arcs originating in the dust layer bridge the ESP gap and discharge the particles; and glow back-ionization, in which positive ions are continuously emitted from the dust layer and neutralize the charged particles. These effects must be better understood and quantified.

Uniform velocity profiles for the flue gas entering the ESP are essential for good ESP performance. Unfortunately, the HII disturbs this flow. The HII anode purge gas system can be used to produce acceptable velocity profiles in addition to its primary function of preventing ash buildup at the anode; however, as mentioned earlier, the required purge gas flow rates increase operating costs and cause a reduction in SCA. An alternative means of producing uniform profiles may need to be developed if the HII is to be economically attractive.

Theoretical predictions indicate that the HII will also have a beneficial effect on an ESP's ability to control fine particulate matter. This may lead to HII applications for existing units with fine-particulate opacity problems, as well as future plants that may face fine-particulate regulation. The HII's effectiveness for fine-particulate control needs to be quantified experimentally for a variety of operating conditions.

Commercial potential

A preliminary assessment of the HII's long-term commercial potential was conducted by Kaiser Engineers, Inc. The study found that if HII technical development is successful, the commercial potential appears promising. In the cost analysis, capital and operating costs were estimated for alternative ways to upgrade ESP performance. A matrix of hypothetical ESP, fly ash, and regulatory situations was used to compare the costs of increasing the ESP's SCA, employing the HII, and applying SO_3 conditioning. Southern Research Institute's computer model was used to predict the performance enhancements for all cases.

The study concluded that the HII may be the most economic choice for upgrading the collection efficiency or reducing fine-particulate opacity for ESPs on low-resistivity fly ash (10^9 ohm·cm or less). Whenever SO_3 conditioning is technically feasible, it becomes the most economic choice; however, the application of SO_3 is precluded when low-resistivity fly ash is involved, when flue gas temperatures are low, and when SO_3 stack emissions are too high. In cases where SO_3 conditioning is unacceptable, the HII is less expensive than added SCA. The study also found that because of the cost of steam used in the anode purge gas to prevent back-ionization in the anode, the operating costs of the HII are higher than those for SO_3 or added SCA. If the use of steam could be eliminated, operation and maintenance costs would be reduced to levels below the cost of SO_3.

The market assessment analysis was limited to consideration of the retrofit market, and it employed conservative (worst market) assumptions about the need for ESP upgrades. As a first step, existing ESP installations were analyzed to predict how many would require upgrading in the 1980–1985, 1985–1990, and 1990–2000 time periods. Retirement of older units, the impact of changes in mass emission and opacity regulations, and known reliability problems were considered. The study predicted that of the 1400 ESPs presently in service, 690 would be retired without upgrading, 140 would not require upgrading, and 570 would require upgrading.

The second part of the analysis estimated what portion of the market (consisting of the 570 upgrades) might be captured by the HII. Factored into the study were the date of HII commercial availability; the types of ESP problems for which the HII is an applicable solution; the prospects for flue gas conditioning, pulsed energization, and other precharge approaches; and relative costs of competing technologies. It was concluded that most HII implementation before 1985 will involve demonstration installations. The HII is expected to capture at least 20% of the upgrade market after 1985.

Future plans

A three-part program is presently being implemented by EPRI to verify HII performance in association with an ESP under representative operating conditions, to communicate the HII research results and commercial potential to industry, and to develop a comprehensive R&D plan to address outstanding technical issues. The first part of the program will be approached through further testing at the Arapahoe 1-MW ESP. A baseline characterization (without the HII operating) will evaluate two effective SCAs, 200 and 300 $ft^2/(1000$ actual $ft^3/min)$, or 39 and 59 $m^2/(m^3/s)$, and two levels of fly ash resistivity, 10^{10} and 10^{12} ohm·cm. Collection efficiencies for total mass and size-dependent particulate matter will be determined. Identical tests will be performed subsequently with the HII energized to quantify the ESP performance improvement provided by the HII. Results from these tests will help determine EPRI's future role in the commercial development of the HII. *Program Manager: Dan Giovanni*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

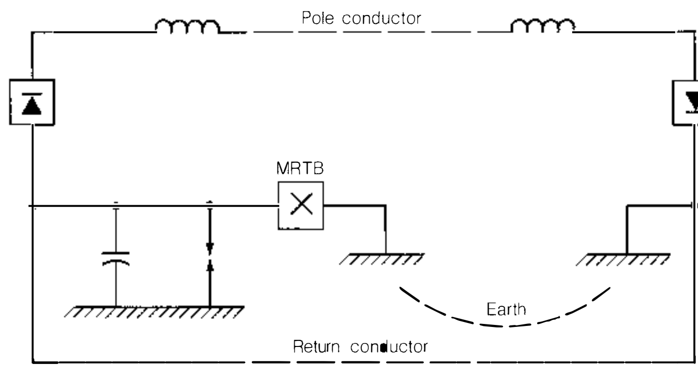
John J. Dougherty, Director

TRANSMISSION SUBSTATIONS

Metallic return transfer breaker

When one of the two poles in a bipolar HVDC system is incapacitated, a current imbalance starts a flow through the ground, establishing a so-called ground return operating mode (monopolar operation). It is then desirable to minimize the time of ground return mode because of the concern for corrosion of buried pipelines from long-term flow of ground currents. This can be accomplished if the damaged line is insulated well enough to carry neutral current, thus providing a metallic return path.

Figure 1 Monopolar operation of a bipolar HVDC system. The return current will flow through the metallic return conductor when the metallic return transfer breaker (MRTB) is open.



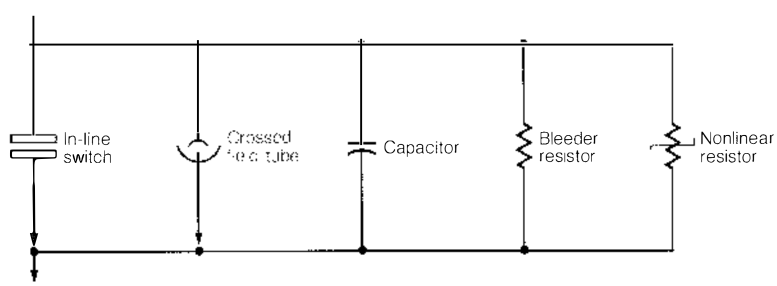


Figure 2 Basic elements of the modified MRTB. Interruption of the dc current is accomplished by commutating the current from the in-line switch to the crossed-field tube and then transferring the current to the nonlinear resistor.

A breaker placed in the neutral of one of the terminals (Figure 1) could accomplish the transfer from ground return operation to metallic return operation and vice versa without requiring a shutdown of the remaining operating dc pole. Such a breaker, the metallic return transfer breaker (MRTB), is being developed as part of EPRI's dc switchgear subprogram (RP667).

In 1975 EPRI contracted with Hughes Research Laboratories to develop and test an MRTB using the novel crossed-field tube (XFT) developed by Hughes. In an earlier project, this device had become the world's first HVDC circuit breaker to successfully clear a fault on a multiterminal HVDC system (RP91). The original concept for the MRTB project involved the use of two XFT stages and a silicon carbide, nonlinear resistor to absorb the stored energy of the current in the transmission line. This configuration was virtually identical to the one used in the fault-clearing test (EL-379).

In 1977 it became apparent that the rapid progress in zinc oxide arresters would shortly render the silicon carbide resistor obsolete. An even more significant factor for the MRTB was that the low residual current would permit a zinc oxide arrester to be permanently connected across the in-line switch, thus eliminating the need for a second crossed-field stage and reducing the cost of the device. Accordingly, in September 1977, Hughes and EPRI agreed to modify the original concept and produce a much simpler MRTB based on a zinc oxide, nonlinear resistor (Figure 2).

This breaker passed laboratory tests in the middle of 1978 and was installed for field testing at the Celilo converter terminal of Bonneville Power Administration. The MRTB successfully passed tests at 300 and 600 A (dc), but during the 1200-A test, the in-line switch (a minimum oil breaker) exploded. It is believed that a test lead failed and caused a short circuit across the MRTB. The resultant structural damage to the in-line switch gave rise to doubts about the suitability of the minimum oil breaker for the in-line switch function.

After further studies, it was concluded that another approach to the in-line switch problem was advisable. A switching element, developed under another EPRI contract (RP564) for ac fault current limiter application, was eventually selected to replace the minimum oil breaker and the XFT. The necessary modification of the MRTB has been accomplished

by Westinghouse Electric Corp. and the new MRTB has been successfully field tested.
Project Manager: Narain Hingorani

Arc by-products in gas-insulated substations

High-voltage circuit breaker designs that employ sulfur hexafluoride (SF_6) gas as an interrupting and insulating medium have been used in the United States for almost a quarter of a century. During the last decade, the use of SF_6 has significantly increased with the introduction of gas-insulated substation (GIS) designs. Because of their compactness, these designs permit installation of high-voltage substations closer to the load centers. Compactness; improved esthetics resulting from low-profile designs; immunity from severe environmental conditions (e.g., salt and ice); and freedom from electrostatic fields, which permits convenient indoor installations, are some of the reasons cited for the increased acceptance of GIS equipment.

SF_6 is an inert gas and, like nitrogen, it can be breathed below the suffocation limit. However, in the presence of electric arcs or corona discharges, this gas is known to decompose into potentially corrosive and toxic gases in some small concentrations. The concentration of these gases is typically 1–2% and, in many instances, much below 1%. Some solid by-products, primarily metal fluorides, are also formed, and these generally settle at the bottom of the equipment in the form of a fine dust.

Fortunately, all these gaseous and powdery substances are contained in sealed equipment, and until the equipment is opened for maintenance or repair, there is no impact on people or the environment.

To fully understand the by-products, a research project was initiated two years ago with Gould–Brown Boveri, Inc., to develop a data base on the chemical by-products generated as a result of arcing in gas-insulated equipment (RP1204-1). The goal of this work was to develop a good understanding of the chemistry so that appropriate handling practices could be developed for the protection of maintenance personnel. Also, the chemical data base would allow the development of simple decontamination and disposal methods for both gaseous and solid by-products.

The work under this project consisted of a series of high-current arcing tests designed to simulate arcing under various real-world conditions. The variables examined were different materials commonly found in gas-insulated apparatus, the moisture concentration in the SF_6 gas, and the magnitude and duration of arcs. The tests were followed by collection and analysis of gas and solids samples. The analytic work was jointly carried out by personnel at Northeastern University and Doble Engineering Co.

The major gaseous arc by-products observed were thionyl fluoride (SOF_2), sulfuryl fluoride (SO_2F_2), and carbon tetrafluoride (CF_4). Trace amounts of sulfur dioxide (SO_2) were also detected. The concentration of the most prominent of these gases, SOF_2, was measured at about 2% of the total SF_6 gas. Since the test chamber volume was much smaller than a typical gas-insulated apparatus, the concentrations of these gases in substation equipment should be well below levels observed in the tests.

In practice, these gases will be recovered from the faulted equipment along with the SF_6 gas, and the only concern remaining is how to scrub these gases and purify the SF_6 for reuse. A limited experimental program evaluated possible scrubber designs and established that the sulfur-containing gases can be reduced to well below 100 ppm. The scrubber would not be intended to take out CF_4 because the level of concentration is low enough to be of no concern from either a biological or insulation point of view.

Test analyses indicated that if SF_6 gas containing arc by-product gases is accidentally released into the atmosphere, manyfold dilution with air will occur, reducing the concentrations significantly. For indoor installations, however, ventilation that is adequate to protect personnel is recommended. The solid arc by-products, mainly metal fluorides, that settle as fine, powdery dust at the bottom of the equipment must be evacuated with care; as the particles are extremely fine, about 1 μm in diameter, they can easily be inhaled when airborne. No toxicity or biological studies were done.

An EPRI-sponsored workshop was held in Chicago in June 1980 to discuss the project results with utilities and researchers, including the equipment manufacturers. It was apparent from the workshop discussions that utility personnel were aware of potential toxicity problems from arc by-products and had been taking precautions. The results from this project offer reassurance that there are no new issues that have not been considered in the work reported from Europe and Japan, where SF_6-insulated substations are extensively used. The detailed results from this project are now available (EL-1646).
Project Manager: Vasu Tahiliani

HVDC system control for damping subsynchronous oscillations

In the recent past, it has been found that HVDC transmission systems and turbine-generator shaft torsional dynamics can interact in an unfavorable manner. In retrospect, this problem should not have been a surprise to HVDC system designers; in general, the sequential switching associated with ac-dc-ac conversion and the modulation of this sequential switching to control direct voltage and current for a variety of power flow modes inherently involves generation of voltages and currents that cover a wide range of frequencies.

In the past, HVDC system designers have concentrated on and solved known problems of radio interference in the MHz range, carrier interference in the hundreds of kHz range, HVDC system resonance at 60 or 120 Hz, current regulator response in the 10–50 Hz range, and power modulation at the very low frequency end of the spectrum. However, the HVDC system response to generator shaft motion in the frequency range of 5–50 Hz was not analyzed until a problem developed during test operation of a recently commissioned HVDC system.

Now that the problem has been identified, analysis techniques and solutions have been and will continue to be developed. There is even a possibility that an HVDC system can be controlled in such a way that it adds damping to the torsional oscillatory modes of generators close to an HVDC converter terminal. EPRI is pursuing this possibility through a contract with General Electric Co. (RP1425).

It was recognized early on that the negative damping of the torsional machine modes was caused by the current control loop of the HVDC converter. Through analytic work, it has been shown that this is a generic problem and can therefore be expected in all HVDC systems. However, it has also been shown that with the exception of the current control loop, the HVDC system adds positive damping to the oscillatory modes; so the solution should be found by changing the current control system characteristics until desirable performance characteristics are achieved.

This research has also produced the following information.

- The interactions between the HVDC converter system and the turbine generator are strongest when the HVDC system is radially connected to one or a small group of machines.
- The level of interaction is dependent on the dc power level. It is worse at high power levels than at low power levels.
- An HVDC link does not adversely affect the torsional stability of a machine connected to a series-compensated line. On the con-

trary, the HVDC system adds damping to the system, although not enough to eliminate the risk of subsynchronous resonances.

▫ The interactions do not seem to be a problem above 20 Hz, and therefore only the low-order torsional modes appear to be of concern.

The ultimate goal of the project is to specify a subsynchronous damping controller that will add positive damping to the torsional modes of interest when applied to the HVDC system. Early results from computer simulation studies indicate that this is quite feasible. *Project Manager: Stig Nilsson*

Active and reactive power modulation of HVDC systems

Power modulation of HVDC converters has been used successfully to increase the power transfer capability of an ac-dc power transmission system. The utilities involved have gained significant benefits through a fairly modest investment in control equipment. However, it is not yet fully understood how to best take advantage of the HVDC system control capabilities.

It is known, for instance, that a change in the active ac power flow (which equals dc power flow) to the converters also affects the ac reactive power flows; this, in turn, causes voltage changes at the converters, which reduces the effectiveness of the active power change. The purpose of an EPRI research project is to investigate control techniques that will mitigate this coupling by both active and reactive power modulation, thereby improving the efficiency of the modulation controls (RP1426).

The contractor, General Electric Co., is conducting simulator studies in an effort to develop in-depth knowledge of the modulation process. Both analog models and digital simulators are being used. The studies address a system in which two small ac networks are connected with a parallel ac/dc tie. In this way, intra-area as well as interarea oscillatory modes can be studied. This set-up provides a lot of flexibility. For instance, a pure dc tie can be studied by making the impedance of the parallel ac tie very large; or a minemouth plant can be simulated by eliminating all but one machine in one of the two ac networks.

The goal of the simulator study is to develop control strategies for the dc link that will provide damping to the oscillatory modes of the ac systems. This will improve the stability limits of the ac systems. The study is considering both small-signal modulation concepts, for improving dynamic stability, and large-signal modulation concepts, which should help to improve the transient stability limits of the ac systems.

Preliminary results indicate that the significant improvements of the modulation control method can be achieved by modulating the dc voltages in addition to the currents. The degree of improvement depends on local network conditions. If, for instance, the ac system load is highly voltage-sensitive, the improvement is likely to be spectacular.

The simulation results will eventually be used to specify a modulation controller. The project's final-phase plan calls for a controller to be built for test operation in an HVDC system simulator. *Project Manager: Stig Nilsson*

HVDC electronic current transducer

A digital electronic current transducer (ECT) for HVDC applications has been built, tested, and installed for long-term testing in an HVDC terminal (RP668-1). The ECT, which meets the known accuracy requirements for dc metering purposes, was developed by General Electric (EL-1343).

A 400-kV, 2000-A test unit was installed for trial operation at the Sylmar Converter Station by the Los Angeles Department of Water and Power (Figure 3). The top of the unit contains a current shunt and electronic equipment for conversion of the current to an optical signal. This signal is transmitted via hair-thin, optical waveguides brought from the control room of the terminal, through the porcelain column, to the top of the unit. The porcelain column houses a 30-kHz, 10-stage cascade transformer that feeds power to the electronic equipment in the energized head of the unit. The optical signal is reconverted to an electrical signal in the control room, which can be up to 300 m away from the ECT.

The intent of the trial operation is to determine if the developed piece of equipment

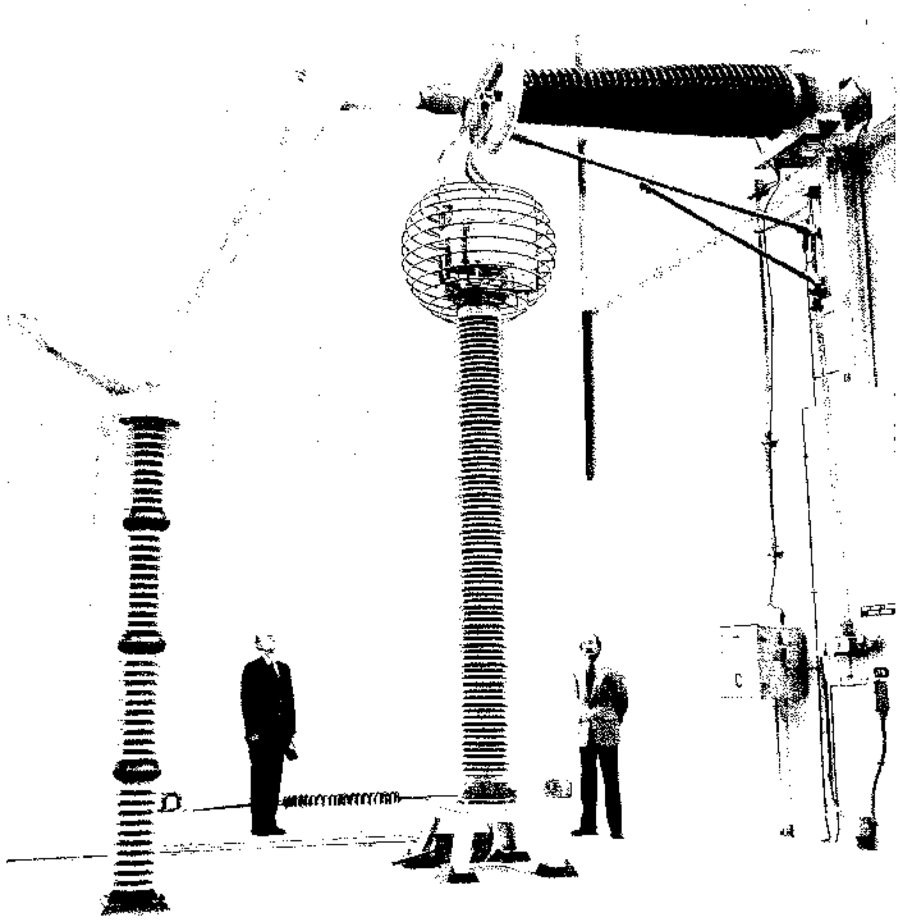


Figure 3 A 400-kV, 2000-A digital electronic current transducer (ECT) of metering accuracy developed for HVDC applications was installed for long-term testing at the Sylmar converter station by the Los Angeles Department of Water & Power.

meets the requirements of an actual utility installation. In this way, any obvious problems with the specification, design, or manufacture of the new equipment will be quickly discovered. Other performance factors, such as reliability and long-term stability, are more difficult to evaluate.

To determine if the ECT has any obvious stability problems, ECT outputs are regularly compared with the outputs from existing conventional current-measuring transductors (a type of magnetic amplifier). The accuracy of the transductor is not as good as the specified accuracy of the ECT, but the transductor outputs are stable and repeatable. Therefore, any significant long-term drift of the ECT or gross errors should be apparent.

The ECT has been operated indoors for the past two years; any obvious reliability problems with the ECT or functional limitations of the design should have been identified by now. The results to date indicate that the ECT meets the operational requirements of an HVDC converter station, even though the test operation has not been completely problem-free.

No fundamental design defects have been discovered that have not or cannot be readily corrected in future device deliveries. For example, the ECT uses low-loss optical waveguides that run from the top of the unit to the control room. At the base of the unit, there are fiber-to-fiber connectors where two types of fibers are joined: a special fiber coming from the top of the unit and a conventional communication-type fiber for the run to the control room, several hundred feet away. Perfect alignment of the fibers in these connectors is needed to prevent excessive attenuation of the light signal in the connector. This problem could be eliminated if new, self-aligning connectors were used. The light power levels in the system could also be improved by using new high-power light-emitting diodes. The ECT operates well in spite of these problems, which can easily be taken care of in future units.

It was found that as the ECT is installed inside the valve hall where the electromagnetic interference level is very high, the shielding of the electronics equipment had to be adjusted to improve ECT noise immunity. The changes were minor and the noise level is now low enough even for metering applications. Finally, an analog-to-digital converter failed after about one year of operation. The cause of the failure is unknown and is believed to be just a random component failure.

The indoor installation exposes the ECT to high average temperatures, but because it does not represent the extreme temperatures and temperature variations found in outdoor locations, outdoor testing may also be conducted. It is planned to use the ECT for a dc revenue meter demonstration commencing early in 1981 (RP1510). *Project Manager: Stig Nilsson*

ROTATING ELECTRICAL MACHINERY

Synchronous machine analysis

With the country's increasing dependence on electricity as an energy form and the shrinking of reserve capacity, power systems and machines have become increasingly susceptible to the effects of transients and other abnormal conditions. These developments have resulted in the need for more accurate methods of predicting performance characteristics of generators, both at the design stage and in detailed studies of machine-system interactions. To accomplish this, it is essential to develop techniques that permit accurate and economic solutions to the generator electromagnetic field problem. This will result in more accurate predictions of generator performance parameters, such as reactances and time constants, as well as improved accuracy of system performance calculations.

General Electric is engaged in a project to develop such techniques for accurately calculating the design and operating parameters for a generator under steady-state and transient conditions (RP1288). This project was begun in early 1978 and is expected to be completed in 1982. Finite element analysis, both two-dimensional and three-dimensional, will be the primary analytic technique used to define the electromagnetic field distribution in the machine. While two-dimensional electromagnetic field analyses have been performed by a number of organizations, a full three-dimensional nonlinear analysis, including the effects of saturation and eddy currents in the iron, has not been done before.

Much of the steady-state work has been completed, and the results meet accuracy expectations. Comparisons have been made with detailed tests on two large generators, with calculated parameters generally being closer to test data than the manufacturer's original data—in some cases very much closer. The transient work is under way, and preliminary results are encouraging. The analytic techniques being developed will be particularly appropriate in analyzing large-signal transients, such as faults, high-speed reclosing, and subsynchronous resonance. *Project Manager: J C. White*

POWER SYSTEM PLANNING AND OPERATIONS

Bulk transmission system reliability evaluation

Evaluation of bulk power system reliability is an important part of the planning, design, and operation of electric power systems. System reliability has a direct impact on the quality of service that customers receive and the rates they pay. Electric utilities are, therefore, under pressure to make more precise evaluations of system reliability and the associated cost-benefit trade-off.

Recently there have been attempts to apply sophisticated (deterministic or probabilistic) approaches to bulk power system reliability evaluations. To give the regulatory commissions a measure of reliability of a system and to translate the need for facility additions in terms of quality of service to customers, reliable and sound probabilistic methods for computing reliability indices need to be developed.

A two-year project with Power Technologies, Inc., was initiated in November 1979 to focus on the development of probabilistic methods to evaluate bulk transmission system reliability (RP1530). The contractor is proceeding with the development of advanced mathematical models for computing reliability indices that take into account frequency and duration of power interruptions and amount of load not serviced.

It is expected that the models and solution methods developed will enable a utility to compute the quantitative system reliability, including consideration of such system problems as circuit overloads, abnormal voltages, and system separation. A prototype computer program capable of computing reliability indices for systems with up to 150 buses is scheduled for completion by the end of 1981. *Project Manager: Neal Balu*

Modular generation expansion

There is a growing need to develop a viable strategy for the expansion of electric utilities' generation capacity. New generation technologies and energy storage devices have increased the variety and flexibility of electric power sources available to utilities. But uncertainties in future fuel prices, capital costs, and the rate of growth of electricity demand make the job of generation expansion planning more formidable than ever. There is also increased pressure to include analyses of environmental regulations and financial and regulatory constraints. Thus, any strategy for the expansion of utilities' future generation should be able to take these factors into account.

A two-year project with Massachusetts Institute of Technology (MIT) was initiated in August 1979 to provide a state-of-the-art, flexible, modular computer program suitable for electric utility capacity expansion planning (RP1529). This program, known as EGEAS, develops an expansion strategy for a utility's future generation, taking into account all the foregoing competing factors. EGEAS builds a common data base developed from a selected set of operating and capacity expansion criteria.

EGEAS is significantly different from the other currently available capacity expansion computer programs in that it includes analysis of the complex choices now facing the electric utilities. For example, the electric generation planning framework of EGEAS is capable of analyzing the effects of rate structure changes, load management techniques, renewable energy technologies, financial and regulatory constraints, effects of transmission interconnections on reliability and production costs, and environmental regulations.

MIT has made a breakthrough in the development of optimization techniques and production-costing algorithms that will enable an accurate representation of storage devices, interconnections, and maintenance scheduling. Tests on the prototype version of the EGEAS program have been completed, and the production-grade version is to be delivered by September 1981. *Project Manager: Neal Balu*

DISTRIBUTION

Wood pole decay

Obtaining the longest possible service life from wood poles is of considerable interest to the utility industry. Accordingly, EPRI has funded three projects that address problems of wood pole decay.

A project recently completed by Oregon State University's Forest Research Laboratory developed an effective means of treating in-service poles with the fumigants Vapam and chloropicrin (RP212). Internal decay has been arrested in Douglas fir and western red cedar poles with this treatment, and reinfestation has been prevented for 10 years with no evidence of reduced effectiveness. Project reports (EL-366 and EL-1480) and a wood pole maintenance manual (Research Bulletin No. 24) are now available from Research Reports Center.

In a second project, similar work is being conducted by the State University of New York at Syracuse on southern yellow pine poles (RP1471). Researchers have identified the principal decay microorganisms that reinfest southern pine poles originally treated with creosote and pentachlorophenol. They are also analyzing the decay mechanisms and determining the chemical and physical changes that take place in the wood as it decays. The effectiveness of the volatile preservatives in arresting and controlling decay is being investigated, and a search for useful decay indicators is being conducted. These activities are being performed with pole samples in the Western Electric Co.'s yard, where poles have been exposed for up to 48 years. Confirming studies are also being conducted on utility poles in service in Georgia, Virginia, New York, Pennsylvania, and at a midwest utility. About half of these regional studies have been completed.

The third project is being conducted by the Institute of Wood Research at Michigan Technological University (RP1528). The two basic objectives of the project are to develop a more thorough understanding of the fundamental chemical and biological processes involved in wood deterioration and to develop new pole treatment materials that will prevent initial decay of poles, instead of simply arresting decay that has already started. If this initial protection is perfected, new poles could be expected to last at least 40 years. One of the approaches being pursued in this study involves disrupting the feeding and development processes by which fungi grow; it is hoped that this biological approach will use nontoxic biochemicals or treatments.

The RP1528 effort encompasses a broad range of studies that include the following.

- Mechanism of brown rot decay
- Fungal enzyme systems
- Synthesis of potential organic preservative chemicals
- Biological control of decay and termites
- Chemical modification of wood
- Selection and screening of commercial biocides as potential wood preservatives

Significant findings are being developed in each area that may provide improvements over the fungicidal wood impregnation presently used for wood preservation.

The three pole decay projects bring together much of the incidental research in preservative treatment of wood poles done over the past 30–40 years. Many more of the fungi responsible for decay and the patterns of their attack have been identified. The prospect for developing new methods for pole preservation is encouraging. *Project Manager: Robert Tackaberry*

Tree growth control

Two years ago EPRI extended a project to control sprout regrowth by injecting small volumes of concentrated chemicals into trees (RP214). The purpose of the extension was to make the technology and injection equipment available to utility foresters for their trial and evaluation. As a result, it has also been possible to extend the experimental investigation to species of trees not included in the initial phase of the project. Eleven utilities are now participating, and their foresters have obtained encouraging results on their own systems.

A final report is available covering the first five years of this development (EL-1112). In addition to outlining the design of the portable air-powered injector system, the report describes the greenhouse and laboratory investigations into the chemicals, their effectiveness on saplings of a variety of species, and their metabolic fate after injection. Data on sprout growth after injection show that from two to three years are required to achieve the normal one year's sprout growth of an untreated tree. An initial cost analysis by the investigator and utility cooperators showed that a 30–50% reduction in tree trimming costs may be possible with the adoption of this procedure.

Field injections and evaluations will continue during the final year of this extended project. Every effort will be made to obtain federal registration for this use of the chemicals. To date, Atrinal has been so registered. *Project Manager: Robert Tackaberry*

Crystallized fly ash studies

Recycling the fly ash that is generated in large quantities at coal-burning electric generating plants is a problem of growing concern to utilities. The National Fly Ash Association reports that the beneficial uses to date for fly ash can absorb only 16% of the annual fly ash production. (This material has been primarily used as a landfill and as a filler-aggregate in concrete or concrete blocks.)

The goal of a feasibility study with ECP Inc. was to investigate a process to develop crystallized fly ash in a controlled manner (RP1210). This crystallized form is chemically inert and has high strength in compression and high moment of rupture. In addition, the insulating properties of the material appear to make it suitable as a possible substitute for porcelain. Specifically, the project investigated in the laboratory the feasibility of developing crystallized fly ash as a possible material for satisfying structural and insulating requirements for overhead distribution line construction. The study encompassed complete analysis of fly ash, fluxing agents, nucleating agents, and the characteristics of crystallized fly ash, with particular emphasis on its physical, mechanical, and electrical properties.

In the laboratory study, fully crystallized fly ash samples were produced by adding various known nucleating and fluxing agents and then curing the material under time and temperature conditions most conducive to crystalline growth. X-ray diffraction analysis identified a variety of crystalline structures that could be achieved by varying the curing cycle or altering the composition of the raw fly ash through beneficiation (removal of certain elements, such as iron and sodium).

The results of this study are being assembled in the final report, which is due to be published in January. They indicate that fly ash is a potential source of raw material that could fulfill the essential requirements of electrical insulating material. Purification (beneficiation) and crystallization develop a material that has excellent physical and insulating properties. The following conclusions have been drawn.

- Fly ash can be crystallized in a controlled manner.
- The physical and electrical properties of crystallized fly ash generally compare favorably with those of porcelain and Russian Slag Sital (a material that has been used in manufacturing insulators and floor tile).
- Beneficiation of fly ash improves its chemical purity and thus its electrical properties.
- The variable and inadequate electrical properties that have been noted in the past can be attributed to impurities contained in raw fly ash.

The study strongly indicates the potential of beneficiated crystallized fly ash as a candidate for a variety of structural insulating products, although the economic viability of such a venture is still highly questionable. Because of this cost uncertainty, no further work is planned at present. *Project Manager: Robert Tackaberry*

Distribution system simulation

Analyzing abnormal distribution system events, such as unexplained fuse blowings, mysterious surge arrester failures, or an intractable flow of third-harmonic current, can be a perplexing problem. Simulation of distribution system circuits would be of great help to the engineer in discovering why or how such an event occurred.

A number of firms have the necessary engineering expertise and equipment to offer analytic services, but distribution problems are generally considered too small to warrant the trouble and expense of outside analysis. Thus, the distribution engineer usually does not get the opportunity to obtain a better understanding of his system—an understanding that would also allow him to improve service reliability and reduce operating and maintenance costs.

One of the objectives of RP1526 was to explore the feasibility of building a simulator that could be used as an everyday operating tool by the distribution engineer. In a series of workshops for utility engineers conducted by the contractor, McGraw-Edison Co., 15 kinds of problems that could be studied on a simulator were identified and ranked for priority. Further study confirmed that the identified problems could be adequately studied on a suitably programmed simulator with state-of-the-art digital computer hardware.

Having determined this, McGraw-Edison proceeded to outline the simulator requirements, set guidelines for the simulator software, and develop a plan for the actual construction of the simulator.

One of the basic requirements of a simulator is that it be usable by all distribution engineers. In the design plan, this requirement is fulfilled by selection of a standard computer language that will make the program adaptable to a variety of computers; interactive access, with graphics capability; carefully structured, modular construction; and numerous programmed instructions, aids, promptings, error-reporting messages, and command menus. Other specified requirements include the ability to solve the 15 generic problems, each of which was subdivided into common subproblems; the ability to solve network simulation calculations in either the time or frequency domain, as required by the problem; a library of equipment models; and a data base of circuit parameters.

Taking all requirements into consideration, the software architecture was designed and a plan for the actual construction was developed.

The plan is comprehensive enough for a skilled engineering–computer programming team to produce a simulator by following all the details presented in the report. However, the contractor has estimated that to do so would require the expenditure of about 15,000 manhours. Building and verifying the simulator is included in EPRI program planning, although a specific project has not yet been scheduled. *Project Manager: H. J. Songster*

OVERHEAD TRANSMISSION

Laterally loaded drilled piers

GAI Consultants, Inc., is conducting research on laterally loaded drilled piers to develop an improved analytic model for predicting the behavior of drilled piers subjected to high overturning moments (RP1280). The model is being verified by full-scale, destructive field tests on drilled piers that have been fully instrumented and installed in a wide variety of subsurface soil conditions.

A total of 14 tests were included in the field-testing, which was completed in July of this year. The first of these tests, conducted in April 1979, was fully sponsored by EPRI; another 12 tests were cosponsored by EPRI and various utilities throughout the United States; and one test was sponsored entirely by three midwestern utilities.

In general, the test piers continued to sustain increasing load even at groundline displacements of as much as 29 in (73.6 cm). Thus, loads much higher than those predicted by state-of-the-art ultimate capacity techniques may be required to produce catastrophic collapse of a laterally loaded pier foundation. If ultimate pier capacity is defined as 2–5° of rotation, one can assume that values produced by state-of-the-art prediction techniques fall short of ultimate capacity for all piers installed in both cohesive and granular soils. This difference between theory and field test results is considerably more pronounced for granular soils than for cohesive soils.

A linear state-of-the-art prediction technique previously developed by GAI for 2° of pier rotation has proved to be reasonably accurate up to one-half of ultimate load capacity. However, since the behavior of laterally loaded drilled piers is highly nonlinear, a linear elastic model can intersect the true moment-displacement curve at only a single point. Therefore, the research objective here is to develop a nonlinear model that accurately predicts the displacements of laterally loaded drilled piers at all load levels. Predictions based on this nonlinear model will be compared with test data and modified, if necessary, to give a best fit to the data. A design/analysis computer program based on this model will also be developed as a part of this project and will be made available to the utility industry in the spring of 1981. *Project Manager: Philip Landers*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

COMMUNITY HEALTH STUDIES

The principal goal of the community health subprogram is to assess the effect on human health of utility operations. This may be achieved by identifying utility-derived substances that may be harmful to man and estimating the magnitude of the health hazard to which human populations are exposed. The overall research effort involves a number of complementary scientific approaches—epidemiologic studies of humans, clinical studies of humans, animal studies, and in vitro testing.

Epidemiologic studies

Epidemiology has the strength of relevance, for it observes the frequency of disease in actual human populations and correlates it with real-world exposures to pollutants. The chief weakness of epidemiology is its lack of sensitivity in situations involving very low levels of risk. This is primarily because of difficulties in characterizing and measuring real-world exposures and in compensating for factors other than air quality that may affect the health of people.

EPRI and the National Institute of Environmental Health Sciences (NIEHS) have jointly funded a 10-year epidemiologic study of the chronic effects of urban air pollution on the respiratory systems of about 12,000 children and 9000 adults living in six cities. Two of these cities have fairly clean air, two have pollution levels usually near the primary standards, and two have levels often exceeding the standards.

The EPRI–NIEHS study has intensively monitored air concentrations of sulfur dioxide, sulfates, and respirable particles. It has also surveyed nitrogen dioxide and ozone concentrations. The measurements have been obtained from central monitoring stations, neighborhood sampling sites, residences (both indoors and outdoors), and personal monitoring devices carried by individuals. Detailed questionnaires have been used to collect data on factors that might alter the responses to these pollutants, such as smoking, occupational history, and home environment characteristics.

Periodic assessments of the biological effects of exposure to the air were made for each of the six cities; a standard battery of lung function tests and questionnaires on respiratory symptoms were used to gather assessment data. Because this study will not be completed until 1984, only preliminary observations are possible now. The most interesting preliminary finding is a generally lower level of lung function in children from households having elevated nitrogen dioxide levels. The major source of such elevated levels of nitrogen dioxide appears to be combustion within the residence, such as cooking with natural gas (RP1001).

Human clinical studies

The strength of human studies is that they are both relevant and can be conducted with individuals in the laboratory. This means that the conditions of exposure can be well characterized and experimentally manipulated. However, because ethical considerations dictate that subjects be exposed only to low levels of pollutant for short periods of time, the effects are limited to minor transient physiological changes. Thus, although these changes may be useful indicators of how the respiratory system reacts during acute air pollution alerts, it is difficult to interpret the meaning of such transient effects in terms of both the development of disease and the health effects of breathing polluted air over long periods of time.

EPRI is currently funding two projects in this area. In one, volunteers were exposed for 10 min to an atmosphere containing particles small enough to penetrate into the lower reaches of the lung. Another group of volunteers was exposed to larger particles, which deposited closer to the trachea. Nine sulfate-containing aerosols and two nitrate-containing aerosols were tested separately. These had no detectable effect on pulmonary function, except for slight changes (clinically insignificant) in the diameter of the bronchial airways. The effects were similar for both healthy volunteers and those with asthma (RP1373).

The other human studies project examined the effects of longer exposures of volunteers to sulfate- and nitrate-containing aerosols (RP1225). Healthy and asthmatic volunteers exercised intermittently during a two-hour period of exposure to the pollutant. Lung function tended to show a slight decrease in healthy and asthmatic subjects alike, but this was generally not statistically significant and never of obvious clinical significance. However, related studies by other sponsors have shown that another air pollutant, ozone, results in physiologically significant effects on pulmonary function that are far more marked than those found for any of the other pollutants tested. Although ozone is highly reactive and might accentuate the effects of other pollutants, its effect on pulmonary function was not enhanced when mixed with a sulfur dioxide–sulfuric acid mixture.

Animal studies

Animal studies have the strength of offering well-defined conditions of exposure that can be experimentally manipulated to a greater extent than is ethical in human studies. These manipulations include short-term exposures to high concentrations of pollutant, long-term exposures to low concentrations of pollutant, and performance of autopsies at critical stages in the development of disease. The prominent weakness of animal studies is the uncertainty in extrapolating the risk of disease in humans from experiments on nonhuman subjects.

EPRI has funded a number of projects in the area of animal studies. The most dramatic results have come from a study examining the effects (at both low and high relative humidities) of ozone and four sulfur-containing components of polluted air. The issues of interest were structural damage to the lung, changes in the lung's ability to dispose of particulate matter, and constriction of the bronchial airways.

Ozone produced far greater effects than any of the sulfur compounds, and these effects were accentuated by exercise and high relative humidities. For example, at 0.8 ppm, ozone caused only transient lung congestion in resting rats, but in those that had exercised it caused gross hemorrhaging and death. Besides confirming the toxicity of ozone, these observations illustrated the usefulness of exercise as a means of amplifying the toxic effect of a given concentration of pollutant. With this in mind, exercise was included in the design of subsequent experimental studies on the effect of sulfur dioxide on dogs.

In the sulfur dioxide tests, a concentration-dependent increase in coughlike effects and above-normal oxygen consumption were observed during exposure; after exposure there was an increase in airway resistance. These effects are consistent with an irritant response, with the increased oxygen consumption serving as an indicator of the additional work required to breathe through a constricted bronchus (RP1112-1).

A number of other air pollutants have been investigated in animal studies. One study has indicated that sulfate-containing aerosols at 4 mg/m^3 increased airway reactivity immediately following exposure, but nitrate-containing aerosols elicited no effect at a similar concentration. An aerosol of sulfuric acid at 1.6 ppm, however, decreased reactivity both immediately after exposure and after 24 hours. There was also a slowing of tracheal mucous velocity. The same concentration of nitric acid had no effect, except for some minor changes when the sheep used were stressed by allergic reactions to bacteria (RP1373). Another project has suggested that regardless of the cation, sulfite compounds are generally more efficient at eliciting irritant or edematous responses than are sulfates or sulfonates (RP1112-2).

Collectively these animal studies suggest that ozone is generally a more toxic component of the atmosphere than the sulfur compounds resulting from the combustion of coal. A more detailed ranking of the toxicity and health significance of these pollutants may be possible when all the above projects have been completed.

In vitro testing

In vitro test systems study the effects of pollutants on bacteria, protozoa, or clumps of cells isolated from a mammal. They are important in screening for a substance's toxic potential and offer the advantages of low cost and quick answers. Specifically, in vitro studies usually measure mutations in the genetic material (DNA) of the cells and are often used as indicators of the cancer-causing potential of chemicals. Test results can be useful in planning subsequent studies in live animals and humans. The primary weakness of this method is that the test setup is a gross oversimplification of the intact animal because it cannot model many of the processes involved in metabolic changes or in genetic damage and repair characteristic of the whole animal.

Most of the in vitro studies sponsored by EPRI have been under the auspices of EPRI's occupational health subprogram because history suggests that cancer is more likely to result from the higher exposure of workers to chemicals than from the normal exposure of the general population. Nonetheless, the staff of the community health subprogram monitors the progress of the projects for use in program planning. One in vitro project has recently reported that the vast majority of extracts of fly ash collected from stacks lack mutagenic properties. In the few samples where mutagenic properties have been found, the data suggest that they result from variations in the burning conditions rather than variations in the feedstock (RP1315). This information has alerted researchers to the importance of combustion conditions and will assist them in designing the most relevant future projects.

Future directions

The community health subprogram will continue to use complementary scientific approaches to identify and estimate the magnitude of human health hazards. Concerted effort is now being directed toward research planning aimed at (1) anticipating what types of hazards may arise in the coming years, (2) planning relevant research projects on these topics, and (3) ensuring that pertinent data are available when they are needed in the regulatory arena. The emphasis will remain on the by-products of conventional fossil fuel combustion, but attention will also be paid to other evolving concerns of the utility industry. *Program Manager: James McCarroll*

ELECTRIC UTILITY RATE DESIGN STUDY: CUSTOMER ACCEPTANCE OF LOAD MANAGEMENT

The Electric Utility Rate Design Study has completed five years' research and has published some 80 technical reports on various aspects of load management, including time-of-use (TOU) pricing and direct load controls. Undertaken in response to a request by the National Association of Regulatory Utility Commissioners to examine ways of controlling peak demand growth and shifting use from peak to off-peak periods, the Rate Design Study is a nationwide research effort sponsored by EPRI, the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association. The 1978–1980 phase was organized into six major topics: customer response (or elasticity), costing and rate design, load research, equipment for load management, customer acceptance and understanding, and cost-benefit analyis. This report discusses completed research on customer acceptance and understanding.

The term *load management* as used in the Rate Design Study encompasses time-differentiated rates and direct load controls and suggests the use of either or both of these methods. A successful load management program is predicated on acceptance by customers, and research in this area can make an important contribution to the evaluation of load management options.

The Rate Design Study uses the term *customer acceptance research* to refer to the investigation of three states of mind concerning load management.

- Customer knowledge or understanding
- Customer attitudes
- Customer perceptions about his/her electricity consumption

The research can probe general issues (e.g., conservation) or specific ones (e.g., water heater controls). Data can be gathered by either quantitative techniques (e.g., formal surveys) or qualitative techniques (e.g., investigating customer inquiry and complaint records, holding local meetings or focus groups, or sampling opinion at a public place, such as a shopping mall). The significant element of customer acceptance research is that it examines states of mind of selected groups. Thus it differs from *customer response research,* which gathers actual usage data from monitoring devices to analyze consumption levels and patterns. (Customer response, or elasticity, is the subject of Topic Paper 1 of the Rate Design Study.)

Topic Paper 5: Customer acceptance studies

Topic Paper 5 of the Rate Design Study (RDS Report No. 88) discusses the role of customer acceptance research in load management decisions, presents a framework for conducting and evaluating such research, and reviews the findings of recently completed studies. The paper emphasizes that to ensure data reliability and validity, customer acceptance studies must be conducted rigorously and with the aid of professionals in survey research. Also, the results should be critically reviewed before being used in the decision-making process.

Topic Paper 5 describes 16 electric utility industry studies on customer acceptance and briefly summarizes the findings of each. In addition, two studies of alternative rate structures in the telephone industry are reviewed. The validity of each study is not analyzed. Although the results of the studies are customer-specific, certain generalizations can be drawn.

In the area of customer knowledge, the studies found that customers generally understood a utility's load patterns; they were not aware that the utility's costs varied by time; the energy costs of appliances were not well known; and the general features of TOU rates actually experienced could be recalled, but not the details.

In the area of customer attitudes, customers believed that electricity shortages would occur, conservation was desirable, and voluntary conservation was the most preferred approach to improving peak load conditions. Load management programs actually experienced, whether voluntary or mandatory, were well accepted.

In the area of perceptions, there was widespread feeling among customers that they had made conservation efforts in response to general energy conditions. Residential customers perceived changes in living habits in response to specific load management programs. However, commercial and industrial customers resisted changes in operating habits because they did not feel that such changes would be beneficial. Residential, commercial, and industrial customers alike perceived that their consumption would change if it meant that they could save money.

Table 1
UTILITY TOU RATE SURVEY

Utility	Number of Customers Under TOU Rates	Monthly Demand per Customer (kW)	Number of Interviews Conducted
Commonwealth Edison Co.	750	>1500	102
Pacific Gas and Electric Co.	127	>4000	54
Southern California Edison Co.	120	>5000	96
Wisconsin Electric Power Co.	450	>300	191
Wisconsin Power and Light Co.	137	>500	72

RDS Report No. 79: Mandated rate programs

The Rate Design Study has also sponsored a specific investigation of commercial and industrial consumers under TOU rates. This study (RDS No. 79) is one of those reviewed in Topic Paper 5 and covers mandated TOU rate programs at five utilities: Commonwealth Edison Co., Pacific Gas and Electric Co., Southern California Edison Co., Wisconsin Electric Power Co., and Wisconsin Power and Light Co. Industrial and commercial customers of these utilities were interviewed to determine their understanding of TOU rates, their attitudes toward the rates, and their perceptions of how their consumption had changed under the rates. At the time of the interviews, each mandated TOU program had been in effect for at least one year. Table 1 presents information on the rate programs and the surveys.

In the area of customer knowledge, almost 90% of the customers said they had a good understanding of how they are charged under TOU rates, but very few were able to correctly answer specific questions about the rates. (Wisconsin Power and Light customers, however, were relatively well informed.) Demand (kW) charges were more clearly understood than energy (kWh) charges, on the whole.

In the area of customer attitudes, approximately two-thirds of those interviewed felt that TOU rates, in general, were a good idea for business. When questioned about the TOU rates actually applied to them, customers were fairly equally divided among those preferring the TOU rates, those preferring the former rates, and those with no preference. Of those preferring the TOU rates, almost two-thirds stated that their bills had been reduced by these rates. California customers preferred the former rates to the TOU rates by a margin of three to one because the former rates yielded lower bills or TOU rates were not advantageous.

Regarding customer perceptions of changes in their consumption, over 50% of those interviewed perceived no change in their peak demand under TOU rates. Relatively few customers (4–21%, varying by utility) indicated that they had reduced their peak demand level or energy use by shifting to off-peak periods. Some customers (6–33%) indicated that they had reduced peak demand level by conserving; similarly, 8–30% reduced peak energy use by conserving. It is noteworthy that about one-third of PG&E's customers perceived a conservation effort in both areas. The research showed that approximately 80% of those interviewed felt that their energy use and demand levels changed in the same direction since TOU rates had begun.

Both RDS No. 79 and RDS No. 88 are available through the Rate Design Study. Integrating customer acceptance research into the evaluation of load management options is a subject that will be addressed in Topic Papers 6 and 7, which are expected to be published early in 1981. The transfer of the research conducted by the Rate Design Study began with a series of regional conferences held last May. A series of workshops on costing and ratemaking is scheduled for various locations beginning in March 1981. *Program Manager: Robert Malko*

R&D Status Report
NUCLEAR POWER DIVISION

LOFT ANALYSIS WITH RETRAN

A project was undertaken with Intermountain Technologies, Inc. (RP496) to assess the usefulness of results from NRC's loss-of-fluid test (LOFT) program in describing the behavior of large PWRs during postulated accidents and to validate the ability of the thermal-hydraulic code RETRAN to predict reactor behavior during a postulated loss-of-coolant accident (LOCA). An integral part of this effort was an evaluation of the accuracy and consistency of the LOFT data. Goals were to understand the state of the art of transient two-phase flow measurement and to determine how much confidence can be placed in such data when evaluating computational models; particular attention was focused on the correlation between predicted and measured values for peak temperature.

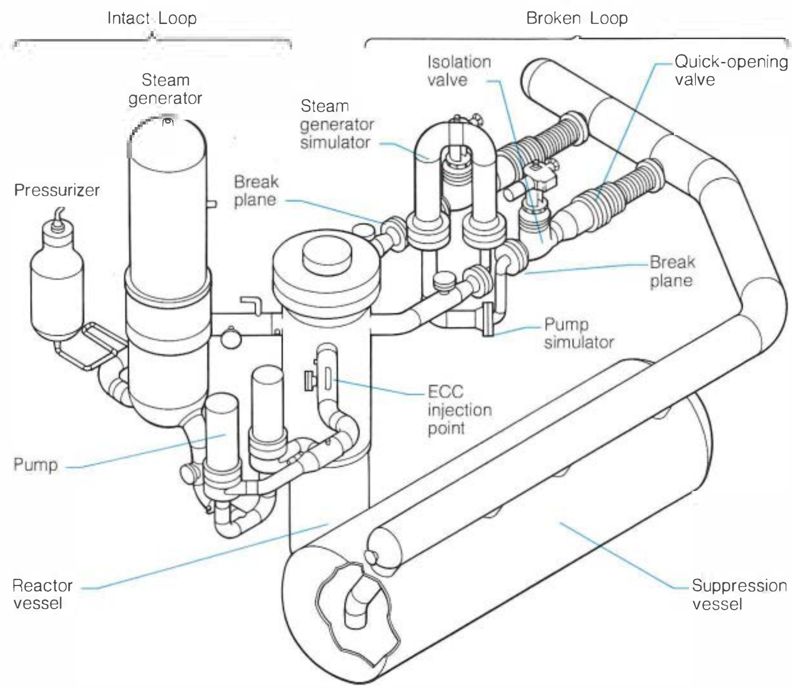
LOFT simulations

The LOFT facility is a nuclear-powered test facility operated by DOE for NRC at the Idaho National Engineering Laboratory. The LOFT system (Figure 1) contains the basic elements of a conventional PWR; a blowdown loop has been added to enable the facility to represent LOCAs.

The first test series (L1) in the LOFT program consisted of nonnuclear LOCA tests, in which system blowdowns were conducted without core heat input. This series has been completed. Series L2 consists of large-break LOCA tests in which the core is operated at various power levels to produce core decay heat input. Other test series in the program involve small-break LOCAs (L3) and transients (L6).

Of primary interest for LOCA analysis were L2-2 and L2-3, the first double-ended cold leg break simulations with core power operation. L2-2 was conducted at reduced power (24.9 MW [th]) with a maximum linear heat generation of 8.04 kW/ft (26.36 kW/m). L2-3 was conducted at 36.7 MW (th) with a maximum linear heat generation of 12.01 kW/ft (39.38 kW/m); this approximates the maximum local core power condition expected in conventional PWRs.

Figure 1 LOFT system set up for simulation of cold leg break LOCAs.



RETRAN analysis

The RETRAN computer code is a one-dimensional thermal-hydraulic code being developed under EPRI sponsorship. It is designed to calculate the behavior of power reactors under abnormal conditions, including transients and LOCAs. Since the beginning of the LOFT program in 1976, RETRAN has been used to predict the outcome of nine tests. Subsequent comparisons of the predictions with the test data indicate the capabilities and limitations of the code and the most appropriate areas for improvement.

Figure 2 Measurements of primary system pressure from LOFT L2-2 and L2-3 are compared with predictions made by the RETRAN thermal-hydraulic code.

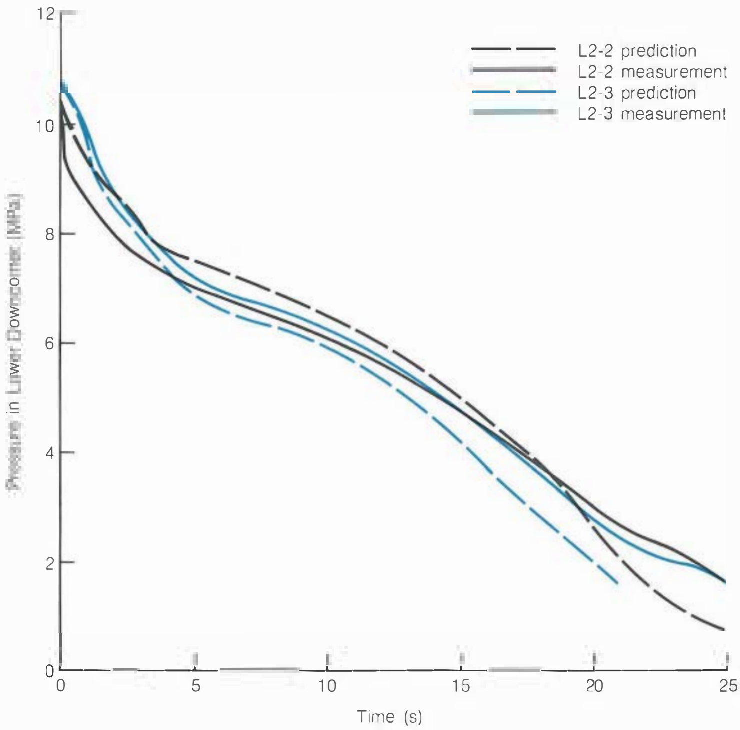


Figure 2 compares measurements of primary system pressure with pretest predictions by RETRAN for tests L2-2 and L2-3. For test L2-2 the predicted pressure is somewhat higher than the measured pressure early in the LOCA. The predicted time of emergency core coolant (ECC) flow initiation agrees quite well with the data, but the predicted pressure drops sharply after ECC flow initiation and deviates significantly from the data. One reason for the difference between the predicted and measured pressures early in time is that the actual initial hot leg temperature (550°F; 288°C) was lower than that specified for the test and used in the RETRAN calculation (598°F; 314°C). The pressure difference after ECC injection is primarily due to the homogeneous-equilibrium feature of the RETRAN code. The code calculates complete, instantaneous mixing between the injected cold coolant and the hot primary fluid, which would cause steam condensation and an abrupt drop in system pressure. By contrast, LOFT measurements indicate that the injected coolant does not mix readily with the primary system fluid.

For test L2-3 the predicted pressure is only slightly lower than the measured pressure early in the LOCA. After ECC injection, the predicted pressure begins to deviate from the data. The lower pressure predicted early in the test is due in part to a discrepancy between the specified hot leg temperature used in RETRAN (573°F; 300°C) and the measured value (608°F; 320°C). The discrepancy late in time is again due to RETRAN's homogeneous-equilibrium models.

Comparisons of the predicted and measured peak cladding temperatures were made for both tests. For L2-2 the value and time of the peak temperature and the rise to it were calculated quite well by RETRAN. The data show an abrupt temperature drop (quench) at about 7 s that was not predicted However, a more gradual temperature decline was predicted for about that time. For L2-3 the initial temperature rise predicted by RETRAN compares well with the experimental data. The predicted peak temperature is somewhat higher than the measured value, and a quench at about 7 s was not predicted (although, again, the code did predict a temperature decline).

Research conclusions

Evaluation of the LOFT results has revealed that data consistency and availability are good. Measurement of temperature and pressure was especially successful. The loss of three gamma-beam density measurements reduced the accuracy of the density measurements somewhat. Some of the momentum flux (drag disk) and velocity (turbine) measurements are questionable. Measurements of fluid mass flow through the test facility core were inadequate. In general, the researchers' treatment of error bounds was adequate.

Comparisons of the RETRAN predictions with the experimental results have revealed that except for differences caused by discrepancies in initial conditions, the fluid temperatures and pressures predicted by RETRAN are in excellent agreement with data until shortly after ECC injection. The fluid densities predicted by RETRAN are in agreement with data trends, although absolute values do not always compare well. The lack of agreement, in part, may be because integral beam density measurements are being compared with calculations of average homogeneous density.

RETRAN predictions of broken-loop cold leg discharge mass flow are in good agreement with data. Predictions of cladding temperatures for the high-powered rods, as well as predictions of the time to departure from nucleate boiling, are in very good agreement with the data. However, RETRAN was unable to predict the rapid decline of fuel pin temperatures early in the tests. Data evaluation has shown that RETRAN in its present form does not accurately model nonequilibrium phenomena.

On the basis of these comparisons, it has been concluded that RETRAN can provide reasonable predictions of overall hydraulic behavior for large-break LOCA tests up to a time shortly after ECC injection (NP-1204). However, the temperature measurements suggest that the actual peak temperatures will be lower than those predicted by RETRAN. Further work is required to assess the code's ability to predict detailed heat transfer from the fuel pins to the core fluid. A series of tests that will include the measurement of core fluid and fuel pin characteristics is currently being planned for the LOFT facility. *Project Manager: Lance Agee*

FIBER OPTICS FOR UTILITY INSTRUMENTATION SYSTEMS

One of the goals of the Engineering and Operations Department of EPRI's Nuclear Power Division is the transfer of technology from other industries to the utility industry. Fiber optic circuits, which feature glass or plastic cables (Figure 3) and a light-beam signal, have been used in telephone systems, computer installations, and defense and space applications. Except for an equipment control application in an EPRI-sponsored experimental high-voltage substation, however, fiber optic technology has not been used in utility installations. In response to requests for information from several utilities that are considering the use of fiber optics in plant instrumentation systems, EPRI sponsored an in-plant demonstration of fiber optic circuits (RP1173).

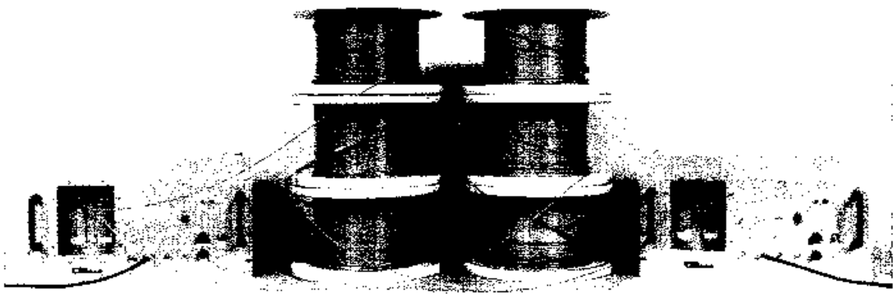


Figure 3 Glass fiber optic cable with equipment terminations.

Public Service Electric and Gas Co.'s Bergen station near Newark, New Jersey, was the site for the fiber optic demonstration. Although fiber optics are being considered for use in both fossil-fired and nuclear plants, a coal-fired plant was chosen in order to avoid the regulatory complications that using a nuclear plant might entail. Another advantage of the Bergen station was that its instrumentation system had recently been upgraded. The plant detectors were wired into a multiplex system where signals could be sought sequentially by its computer.

E-Systems, Inc., of Greenville, Texas, which has had experience with fiber optic installations for the Department of Defense, was selected to design the fiber optic system and provide the components. It was possible to install the system in the plant to parallel the hardwired coaxial cable link without significant redesign and plant modification expenses. Thus plant personnel could easily shift back and forth from the fiber optic system to the coaxial cable, which made it possible to test both plastic and glass fiber optic cables and to try various repair methods on the fiber optic system with minimal plant disruption. Plastic cables were used for short runs (up to 350 ft; 107 m) and glass cables for longer runs (up to 1300 ft; 396 m).

Certain problems with the fiber optic system had been expected on the basis of experience in other applications; additional problems specific to a utility plant were discovered. It was known that glass fiber optic cable is far superior to plastic cable for low-loss transmission over thousands of feet with no intermediate signal amplification. It was also known that glass cable is more brittle and subject to breakage if kinked or bent sharply. Little information was available on glass cable field-splicing and break location. A special piece of equipment called a time-domain reflectometer (a light-beam radar) was obtained that could determine the location of a break in a glass cable within a few feet in a 1300-ft run (Figure 4). Finding a point of damage on a particular cable hundreds of feet from the light transmitter was difficult with unmarked cable, even though generally there was physical evidence of the damage. So it was quickly concluded that cable should carry identification and distance marking.

As it was assumed that the fiber optic cables would be damaged over the life of the plant installation, the design of the test system was conservative (i.e., it allowed adequate transmission with a number of splices). Because the system was not optimally protected in its temporary installation, there was a fair amount of accidental damage to the cables during the trial period, and field-splicing was a necessity. Adequate splicing equipment and procedures were available for the plastic cable, which proved to be far superior to the glass in terms of handling, splicing, and ruggedness. Very careful alignment of the broken ends of a plastic cable resulted in a signal path with low losses, and plant personnel were able to install such splices.

Splicing the glass cable was more difficult because the diameter of the fiber optic strand is smaller and alignment is more critical for longer runs. Another problem encountered was the lack of standardization in cable jacket size; one of the cables, for example, required custom-made connectors because it had a nonstandard-size jacket as a result of its fire-retardant properties. To produce a low-loss splice with some of the cable connectors provided by the initial supplier, it was necessary to make several trial closures while measuring losses. Obviously, these connectors would

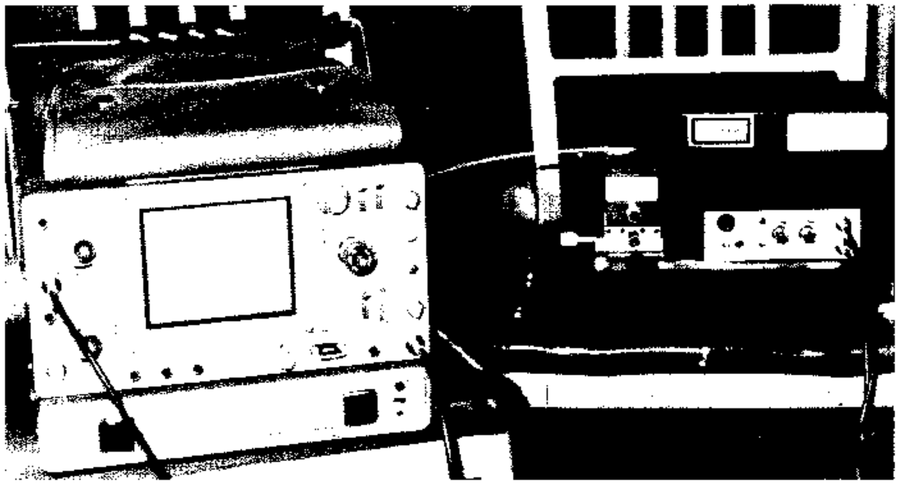


Figure 4 Time-domain reflectometer, used to locate breaks in fiberoptic cable.

not be suited to field installation. An acceptable field splice was finally achieved with another supplier's connector, which features close alignment and light transfer through a connecting lens.

All field-installed splices in the glass cables resulted in signal reductions of at least a few dB. It was found that cable performance could be restored to a condition of very low loss at these points by using a laser welder, which heats the broken ends of the glass fiber to a molten condition so they can be fused. Although it did not appear that this equipment was appropriate for second- or third-shift field repair (because it requires special equipment and a trained technician), it could be used to reduce cable losses by replacing field splices made over several years of service.

It is probable that a large number of splices will eventually produce losses high enough to reduce transmission effectiveness. Telephone installations that run signals over fiber optic cables for distances of 6–9 mi (10–15 km) are spurring the development of improved splicing equipment and procedures, as well as improved light sources. The standard light-emitting diode light source was found to be adequate for the distances in this demonstration and should be adequate for most utility applications. For longer runs, a laser light source is available if the design calculations require it.

The plant's Honeywell-4400 computer, which has a sampling rate of 500,000 bits per second, is programmed in a question-and-answer mode to the plant's multiplex system. The computer requests a signal and then waits up to 10 ms for the reply over the multiplex system, which sequentially feeds back the plant data over a single coaxial cable. The computer evaluates the signal to determine if the plant condition in question is acceptable; it will also store, display, and print the plant information. Because fiber optic equipment is capable of being used in the range of 10–15 megabits per second or higher, the equipment and design were not taxed in this application, and very high accuracy was obtained.

Although nuclear radiation was not a factor in this demonstration, two government-funded investigations of radiation effects report that radiation-resistant fiber optic cables are available. The Department of Defense studied the high-dose burst effect, such as an airplane near an atomic bomb explosion might experience; the National Aeronautics and Space Administration looked at the longer-term, lower-level radiation that a space probe might experience.

In summary, fiber optic cables offer several advantages: good electrical insulation properties, insensitivity to electromagnetic interference, no spark or fire hazard, and very high data rate capabilities. As fiber optic cable is essentially immune to electrical and electromagnetic interference, sparking, shorting, and (for glass cables) short-term fire exposure, it can be used near transformers, motors, and switching panels and in explosive atmospheres. The cable's electrical isolation negates worries about circulating ground currents and other noise problems.

The drawbacks of fiber optic systems include higher cost, susceptibility of glass cable to breakage, lack of standard cable sizes, susceptibility of the sending and receiving equipment to noise interference (as in all electronic equipment), reduced signal transmission or signal loss for most cables at temperatures above 150°F (66°C), and the need for special testing and repair equipment.

The study concluded that fiber optic cable has significant advantages in many troublesome signal areas; its disadvantages must be understood and taken into account, however, to ensure successful application. The results of this project are reported in NP1322. *Project Manager: R. E. Swanson*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP501-4	Human Factors Review of Enhancement Approaches for Nuclear Control Rooms	15 months	395.0	Honeywell, Inc. *H. Parris*
RP603-3	Residual Stress Distribution Near Growing Cracks	5 months	50.0	Science Applications, Inc. *D. Norris*
RP695-3	RETRAN Analysis	4 months	15.5	Oregon State University *J. Naser*
RP784-4	Laboratory Evaluation of Resox Modifications	5 months	97.4	Foster Wheeler Development Corp. *T. Morasky*
RP895-20	SPEAR ALPHA: Power Shape Monitoring System Linkage	10 months	85.1	Nuclear Services Corp. *T. Oldberg*
RP1159-4	Instrumentation Development for Two-Phase Flow	14 months	215.2	Auburn International, Inc. *M. Merilo*
RP1200-8	Preparation and Evaluation of New Support Materials for Acid Fuel Cells	11 months	84.0	Giner, Inc. *J. Appleby*
RP1256-4	Empirical Evaluation of NO_X Control by Flue Gas Treatment for Coal-Fired Utility Steam Generators	15 months	573.7	KVB, Inc. *E. Cichanowicz*
RP1276-8	Technical Studies of Dual Energy Use Systems	1 year	155.8	Synergic Resources Corp. *R. Mauro*
RP1340-3	Technical Services for the VTFE Demonstration	2 months	3.5	Bechtel National, Inc. *W. Chow*
RP1363-2	Time-of-Day Pricing: Report Review	4 months	5.2	Laurits Christensen Associates *S. Braithwait*
RP1432-3	Implementation of R&D Portfolio Selection Software	3 months	59.0	Decision Focus, Inc. *S. Sussman*
RP1504-2	Subsynchronous Resonance Damping	1 month	10.0	Siemens-Allis Corp. *N. Hingorani*
RP1579-7	Corrosion Studies of Waste Cannister Materials	3 months	7.7	SRI International *R. Williams*
RP1611-1	Development of a Noninvasive PWR Water Level Indicator	9 months	118.7	National Nuclear Corp. *P. Bailey*
RP1623-1	Valve Packing Improvement	15 months	139.0	Stone & Webster Engineering Corp. *B. Brooks*
RP1627-4	Assessment and Application of Transient Fuel Behavior Computer Codes	4 months	15.9	Westinghouse Electric Corp. *R. Oehlberg*
RP1630-10	Field Testing and Development of EPRI Automated Telephotometer	1 year	245.1	SRI International *G. Hilst*
RP1630-90	Eastern Regional Air Quality Studies: Precipitation Chemistry Measurements	3 months	69.4	East Central Area Reliability Coordination *J. Jansen*
RP1654-5	Exploratory Gasification System Support Studies: Analysis of Refractories for Slagging Gasifiers	15 months	40.0	Lockheed Missiles & Space Co., Inc. *W. Bakker*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1660-2	Documentation of Operating Problems of Pressurized Stretford Units	1 month	8.7	Synthetic Fuels Association *S. Kohan*
RP1682-2	Test and Evaluation of the Cameo Demonstration for Dry SO_X Removal	5 months	147.6	KVB, Inc. *R. Hooper*
RP1733-1	Reactor Safety Experiments: Blowdown Jet Impingement Load	18 months	1004.3	Studsvik Energitecknik Ab *A. Singh*
RP1746-2	Turbine Generator Shaft Torsional Monitoring Program, Phase II	18 months	99.9	Tennessee Valley Authority *J. Edmonds*
RP1757-2	Flaw Evaluation for Support Services	1 year	97.5	Aptech Engineering Services *T. Marston*
RP1761-1	Development of Reload Safety Analysis Methodology and Code Package	7 months	249.7	S. Levy, Inc. *R. Lee*
RP1772-2	Comparative Risk Analysis of Selective Electric Energy Systems	8 months	35.0	Resource Management Consultants *P. Ricci*
RP1810-1	Evaluation of Value Impact Methodology	1 year	99.9	Science Applications, Inc. *A. Adamantiades*
RP1822-4	Toxic Substances Research	6 months	22.3	Florida Power & Light Co. *R. Brocksen*
RP1840-1	Oil Recovery in Oil Agglomeration of Fine Coal	4 months	29.5	E. C. Lavelle *R. Sehgal*
RP1842-1	Sequoyah Nuclear Plant: Probabilistic Safety and Availability Study	19 months	696.8	Kaman Sciences Corp. *B. Chu*
RP1845-1	Steam Generator Simulation Experiments Under Dynamic Thermal Conditions	1 year	262.0	Acurex Corp. *S. Kalra*
RP1852-1	Evaluation of Reagents for Difficult Coals	7 months	19.2	Indiana Analytical Laboratories Inc. *R. Sehgal*
RP1852-4	Froth Flotation for Fine-Coal Cleaning	17 months	149.5	Wemco/Envirotech Corp. *R. Sehgal*
RP1853-1	Drying and Handling of Fine Coal	16 months	204.7	Kaiser Engineers, Inc. *R. Sehgal*
RP1853-2	Fine-Coal Separation in Low-Viscosity Organic Liquids	7 months	93.9	Otisca Industries, Ltd. *R. Sehgal*
RP1868-1	Field Test of Full-Scale Pulser Energization of Electrostatic Precipitators	9 months	150.0	Southern Research Institute *W. Piulle*
RP1868-2	Field Test of Full-Scale Pulser Energization of Electrostatic Precipitators	3 months	50.0	Southern Research Institute *W. Piulle*
RP1874-1	Dissimilar Weld Failure Analysis and Development	2 months	90.6	Metal Properties Council, Inc. *R. Viswanathan*
RP1940-1	Survey of Utility Conversion, Load Management and Solar End-Use Projects	7 months	300.4	Energy Utilization Systems, Inc. *T. Lechner*

New Technical Reports

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

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

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ADVANCED POWER SYSTEMS

Workshop Proceedings: The Role of Personnel Error in Fossil Fuel Power Plant Equipment Reliability

AP-1470 Workshop Proceedings (TPS77-715); $4.50

EPRI sponsored a workshop in St. Louis in November 1979 in connection with a technical planning study on the role of personnel errors in power plant equipment reliability (AF-1041). This report contains formal workshop presentations on the study results, operator tasks and environment, the use of simulation in training, the role of human factors in equipment design, motivation for increased professionalism, and the man-machine system concept. It also contains recommendations developed in working-group sessions. The contractor is Failure Analysis Associates. *EPRI Project Manager: Jerome Weiss*

Ceramic Materials for Fusion Reactors

AP-1499 Interim Report (RP992); $5.25

This report describes the initial results of a study on the use of low-activity ceramic materials in fusion reactor first-wall and blanket structures. It covers background and radioactivity analyses, an evaluation of the current status of structural ceramics, conceptual design studies, a parametric evaluation of ceramic first-wall and blanket design concepts, a survey of radiation damage in silicon carbide and graphite for first-wall applications, and a development plan for ceramics use in fusion reactors. The contractors are General Atomic Co., General Electric Co., and Rensselaer Polytechnic Institute. *EPRI Project Managers: W. T. Bakker and D. J. Paul*

Extension and Validation of Fault Tree Analysis for Reliability Prediction

AP-1510 Final Report (TPS77-707); $5.75

This report describes work done to determine the accuracy of a reliability prediction for a fossil fuel power plant consisting of a combustion turbine and a heat recovery steam generator in parallel operation with a package boiler. Fault tree methodology was used to estimate both the mean plant reliability and a confidence interval for the calculated reliability prediction. Results were compared with reliability data from plant operating experience over a two-year period. The contractor is Science Applications, Inc. *EPRI Project Manager: Jerome Weiss*

Ceramic Turbine Components Research and Development

AP-1539 Final Report (RP421-1); Part 1, $10.50; Part 2, $4.50; Part 3, $6.50

Part 1 summarizes progress in the development of ceramic rotor blades for advanced utility combustion turbines. It covers design (including turbine blade and root-form designs), stress analyses of the blade root forms, materials characterization, and the fabrication and testing of root-form specimens. Part 2 describes a study to determine the resistance of state-of-the-art ceramic thermal-barrier blade coatings to the combustion gases of residual oils. Tests were conducted by doping No. 2-GT distillate with impurities commonly found in residual oils. Part 3 describes design and analysis work on a ceramic catalytic low-emission combustor element for industrial combustion turbine application. It presents preliminary designs of the total combustion system and conceptual designs of the ceramic catalytic element. Also discussed are steady-state and transient thermomechanical analyses, catalytically supported combustion under typical turbine operating conditions, and the interaction between the ceramic catalytic support and the metal combustor liner. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Arthur Cohn*

Ceramic Turbine Components Research and Development

AP-1539-SY Summary Report (RP421-1); $2.75

This report summarizes three investigations concerned with the application of ceramics to advanced combustion turbine systems: ceramic rotor blade development, evaluation of ceramic thermal-barrier coatings, and development of a ceramic catalytic combustor element. Each of these studies involved design, analysis, and testing of the ceramic component, with emphasis on its relationship to the metal support structure. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Arthur Cohn*

Field-Reversed Mirror Pilot Reactor

AP-1544 Annual Report (RP922); $13.50

This report presents the results of a two-year effort to design a near-term, small-scale fusion power plant whose construction and operation would represent an important step toward the commercialization of fusion energy. Plasma physics, fusion component design, blanket and shield design, balance-of-plant design, reactor performance, safety considerations, and cost evaluations are discussed. The contractors are Lawrence Livermore Laboratory, General Atomic Co., and Pacific Gas and Electric Co. *EPRI Project Manager: D. J. Paul*

Satellite Power System: Utility Impact Study

AP-1548 Final Report (TPS79-752); $4.50

The state of the art of the solar satellite power system (SPS) concept being evaluated by DOE and NASA is summarized, with emphasis on requirements for integrating the system into utility networks. In an SPS a satellite would convert solar energy into microwaves and beam energy to a receiving antenna on the ground for conversion to electricity. The report analyzes a reference design for a 5-GW SPS unit. The contractor is System Control, Inc. *EPRI Project Manager: F. R. Goodman*

COAL COMBUSTION SYSTEMS

Nuclear Assay of Coal: Coal Composition Determination by Prompt Neutron Activation Analysis—Theoretical Modeling

CS-989 Final Report, Vol. 2 (RP983-1); $3.50

This volume describes coupled neutron-gamma transport in coal, as calculated by simplified one-dimensional models based on the ANISN and CAPGAM computer codes. The dependence of capture gamma-ray intensity on bulk density, sample thickness, and coal composition and geometry is discussed. The contractor is Science Applications, Inc. *EPRI Project Manager: O. J. Tassicker*

Materials Problems in Fluidized-Bed Combustion Systems

CS-1449 Final Report (RP388-1); $5.25

This report describes a study of the corrosion behavior of a wide range of candidate structural materials under a variety of fluidized-bed combustion conditions. A small atmospheric fluidized-bed combustion system was used to test 38 alloys at various temperatures in above-bed, in-bed, and exit-cyclone environments for exposures of 1000 and 2000 hours. Test conditions and the results of posttest metallurgic evaluations are summarized. The contractor is the National Coal Board. *EPRI Project Manager: John Stringer*

Materials Problems in Fluidized-Bed Combustion Systems: Appendixes 1–6

CS-1449 Final Report (RP388-1); App. 1, $4.50; App. 2, $11.25; App. 3, $10.50; App. 4, $5.25; App. 5, $4.50; App. 6, $4.50

Appendix 1 describes the atmospheric fluidized-bed combustion test facility used to study the corrosion behavior of various alloys; it outlines operating procedures, sampling methods, and test conditions. Appendix 2 describes procedures for test specimen preparation, handling, and posttest examination. Appendixes 3 and 4 present the results of posttest evaluations of boiler alloy specimens, and Appendix 5 the results of evaluations of turbine alloy specimens. Appendix 6 presents data characterizing the specimens before testing. The contractors are the National Coal Board, Foster Wheeler Development Corp., and General Electric Co. *EPRI Project Manager: John Stringer*

High-Temperature Erosion-Corrosion of Alloys

CS-1454 Final Report (RP979-5); $8.75

Ten alloys representing the current commercial state of the art were evaluated to identify characteristics that may influence resistance to high-temperature erosion-corrosion in coal combustion and gasification environments. The alloys were tested in argon and in simulated fluidized-bed combustion and gasifier atmospheres. Metallurgical characterizations, hot hardness measurements, and fracture toughness determinations are presented. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: John Stringer*

Coal Preparation Using Magnetic Separation

CS-1517 Final Report (RP980-1); Vol. 1, $4.50; Vol. 2, $4.50; Vol. 3, $4.50; Vol. 4, $5.25; Vol. 5, $7.25

A project was undertaken to assess the usefulness of magnetic separation in improving coal quality. Volume 1 describes the testing of a pilot-scale, commercially available induced-magnetic-roll separator to determine its effectiveness in removing pyrite and ash from coal magnetically enhanced by Magnex processing. Seven coals were tested. Volume 2 outlines a series of wet magnetic separation experiments run on a bench-scale superconducting high-gradient magnetic separator (HGMS); pyritic sulfur and ash reduction was determined for two test coals. A conceptual design for a 110-t/h HGMS for a commercial-scale coal-cleaning plant is also presented. Volume 3 describes the testing of another bench-scale HGMS on five coals. A preliminary economic analysis for a hypothetical commercial facility is also presented. Volume 4 describes bench-scale experiments to determine the effects of adding small amounts of ferrofluids to both wet and dry coal to enhance magnetic properties and subsequent magnetic cleaning. A literature survey and a review of the potential uses of ferrofluids are included. Volume 5 reviews all the experimental data obtained in this project and assesses the feasibility of applying magnetic coal-cleaning concepts in the utility industry. The contractors are Nedlog Technology Group, Magnetic Corp. of America, Sala Magnetics, Inc., Colorado School of Mines Research Institute, and Bechtel National, Inc. *EPRI Project Manager: W. W. Slaughter*

Power Plant Operator Curriculum Planning Guide

CS-1529 Final Report (RP1266-6); $8.75

This manual, designed for use in personnel training programs, is based on detailed task inventories of the skills and knowledge required by power plant operators. It contains an orientation section on the power plant, its component systems, and safety rules, and it outlines courses and modules for each curriculum grade from entry level to control room operator. The contractor is the Center for Occupational Research and Development. *EPRI Project Managers: J. P. Dimmer and K. P. Lehner*

Advanced Concepts Test Facility: Measurements and Suggested Test Plan

CS-1530 Interim Report (RP422-3); $5.25

This report describes instrumentation requirements and test strategies for the Advanced Concepts Test Facility, which is being constructed for the demonstration of an advanced dry-cooling concept that features ammonia heat transport and water augmentation. Topics discussed include measurement accuracy, the statistical treatment of results, and data acquisition and logging. Listings of the instrumentation are presented, as well as tables of run plan strategies for several types of test. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. A. Bartz*

Studies of Long-Term Chemical and Physical Properties of Mixtures of Flue Gas Cleaning Wastes

CS-1533 Final Report (RP1260-1); $6.50

A laboratory study was conducted to develop information on the long-term characteristics of flue gas cleaning waste mixtures. Simulated waste mixtures that contained five fly ashes representing five coal basins and three coal grades were studied in depth. The chemical and physical properties of the sludge-ash mixtures after two years of curing were evaluated and compared with the properties exhibited in the first 56 days of curing (reported in FP-671, Vol. 2). The contractor is Radian Corp. *EPRI Project Manager: D. M. Golden*

Instrument and Control Technician Curriculum Planning Guide

CS-1537 Final Report (RP1266-6); $8.75

A detailed inventory of the skills and knowledge needed by an instrumentation and control technician is presented. This inventory forms the basis for a model two-year curriculum, which was developed with the help of representatives of power plants and postsecondary vocational and technical institutions. Descriptions and outlines are supplied for each course and its component modules, along with learning objectives based on job performance requirements. The contractor is the Center for Occupational Research and Development. *EPRI Project Managers: J. P. Dimmer and K. P. Lehner*

A Study of Forces on Immersed Tubes in Fluidized Beds

CS-1542 Topical Report (RP718-2); $5.75

Tests were conducted on heat exchange tubes in coal-burning atmospheric fluidized-bed combustors to provide data for use in the design of tubes and their support systems for large-scale boilers. Forces on tubes of various lengths were measured over a range of fluidization conditions. The parameters varied were superficial gas velocity, bed media particle size, tube spacing, and array height above the gas distributor. The contractor is Oregon State University. *EPRI Project Manager: W. C. Howe*

An Analytic and Experimental Study of Multiple Plumes

CS-1547 Final Report (RP732-1); $5.25

A numerical integral model for predicting the behavior of plumes from multiple mechanical draft cooling towers is presented. The model is applicable to an arbitrary wind velocity profile. A series of laboratory tests on small-scale multiple-cooling-tower models with two and three plumes was conducted, and the numerical predictions were compared with the experimental results. The contractor is the Institute of Hydraulic Research, University of Iowa. *EPRI Project Manager: J. A. Bartz*

Biofilm Development and Destruction

CS-1554 Final Report (RP902-1); $12.00

This report discusses a theoretical analysis and laboratory study of slime films, which are a problem in condenser tubing. It provides a tentative conceptual model for the mechanisms governing the growth and destruction of microbial films and their effects on energy losses. Various instruments are reviewed to determine their effectiveness in detecting and measuring films and their usefulness as research tools and in power plants. The contractor is Rice University. *EPRI Project Manager: R. M. Jorden*

Test Report: Wet-Dry Cooling Tower Test Module

CS-1565 Final Report (RP738-1); $3.50

The engineering performance of a single-cell wet-dry cooling tower designed to reject the heat associated with the generation of 15 MW (e) was evaluated in an 18-month field test. The project was undertaken to study the performance and reliability of a commercially available cooling tower that reduces water consumption. A mathematical model for predicting, over a range of conditions, the thermal performance of the cooling tower was developed and evaluated. The contractor is Southern California Edison Co. *EPRI Project Manager: J. A. Bartz*

ELECTRICAL SYSTEMS

Bipolar DC Transmission Research Above ±600 kV at Project UHV

EL-1545 Final Report (RP1282-1); $3.50

This report describes the HVDC bipolar research facilities developed at Project UHV in Lenox, Massachusetts, to provide data for the design of overhead dc transmission lines in the range of ±600–±1500 kV. Existing ac test facilities were adapted for dc testing, and new equipment was installed. The new power supply equipment is described, along with a study of power supply requirements for flashover tests on HVDC insulators. The contractor is General Electric Co. *EPRI Project Manager: R. E. Kennon*

Phase-to-Phase Switching Surge Design

EL-1550 Final Report (RP1202-1); $8.75

This report discusses phase-to-phase switching surge design information for 115–138-kV compact transmission lines. It presents the results of tests examining variations in phase spacing, line length, conductor height, surge magnitude on each phase, conductor size and hardware, and vibration dampers. It also discusses design of flashover test procedures, development and application of data analysis methods, possibilities for accelerated test methods, and key areas for future testing. The contractor is Power Technologies, Inc. *EPRI Project Manager: R. E. Kennon*

Long-Range Transmission Expansion Models

EL-1569 Final Report (TPS79-728); $6.50

The state of the art of transmission expansion models for long-range planning is examined, and the requirements of a practical model in terms of user needs and resources are defined. Recommendations for future R&D are also presented. The contractor is Ebasco Services Inc. *EPRI Project Manager: N. J. Balu*

Digital Techniques for Control and Protection of Transmission-Class Substations

WS-79-184 Workshop Proceedings; $10.50

EPRI sponsored a workshop in San Diego in November 1979 to investigate digital techniques for the control and protection of transmission-class substations. This report contains all the papers prepared for presentation at the workshop. Topics include conceptual designs of digital systems, system requirements, the use of links and data highways within systems, and testing and maintenance philosophies. The state of the art in supporting technologies, primarily microprocessors and fiber optics, is reviewed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: S. L. Nilsson*

ENERGY ANALYSIS AND ENVIRONMENT

The Effect of Electric and Magnetic Fields Near an HVDC Converter Terminal on Implanted Cardiac Pacemakers

EA-1511 Final Report (RP679-1-3); $4.50

This report describes the second of two studies investigating the effects of the electromagnetic environments associated with HVDC converters and transmission lines on implanted cardiac pacemakers. The potential of field interference with the devices to cause reversion (asynchronous pulsing) was studied in the laboratory by subjecting six pacemakers to seven electromagnetic signal mixes from an HVDC converter facility. The contractor is IIT Research Institute. *EPRI Project Managers: Robert Kavet and Leonard Sagan*

Biogenic Sulfur Emissions in the SURE Region

EA-1516 Final Report (RP856-1); $7.25

Laboratory and field research was conducted to estimate the magnitude of biogenic sulfur emissions in the northeastern United States, the area studied in EPRI's Sulfate Regional Experiment. This report includes a review of the sampling and analytic procedures used at the 21 test sites; a compilation of the statistical analyses of the data; a discussion of environmental procedures and field data for measuring biogenic sulfur flux in the area; and a calculated emissions inventory of sulfur flux. The contractor is Washington State University. *EPRI Project Managers: Charles Hakkarinen and A. Stankunas*

Electric Load Forecasting: Challenge for the 1980s

EA-1536 Final Report (RP1303-1); $5.75

This first report of the Utility Modeling Forum compares load-forecasting methods used by over 20 electric utilities. It examines ways to identify and quantify major sources of uncertainty, analyze the impact of time-of-use rates on load shape, model the impact of new technologies, and integrate econometric and end-use forecasting methods. The contractor is Booz, Allen & Hamilton, Inc. *EPRI Project Manager: Dominic Geraghty*

Development of an Airborne Lidar for Characterizing Particle Distribution in the Atmosphere

EA-1538 Final Report (RP1308-2); $3.50

An airborne lidar system that uses dual-wavelength lasers to collect information on particle distribution in the lower atmosphere was developed and field-tested. This report summarizes the system configuration and presents block diagrams and a list of components. It also describes the data-processing system, which is designed for both real-time facsimile display and magnetic tape recording, and presents the results of the one-week field program. The contractor is SRI International. *EPRI Project Manager: R. M. Perhac*

Alternative Futures: Choices and Uncertainties

EA-1541-SR Special Report; $4.50

This report presents three analyses of alternative U.S. economic and energy futures that draw respectively on the Wharton Model, the DJA Modeling System, and the ETA–MACRO energy-economic models. The analyses use short-, intermediate-, and long-run time frames to examine the role of (1) alternative social and government choices and (2) factors beyond the control of decision makers in determining the future. *EPRI Project Manager: E. V. Niemeyer*

Proceedings: Workshop on Coal Transportation Research

EA-1549 Workshop Proceedings (RP1219-4); $3.50

A workshop was held in Palo Alto, California, in January 1980 to describe previous and current coal transportation research at EPRI. This report contains summaries of the presentations and the discussion session. It also presents the workshop's research recommendations, which include projects on the definition of rail and waterway capacity, railroad costs and ratemaking procedures, alternative technologies, legislative impacts, and improved methodologies. The contractor is Russian Hill Associates. *EPRI Project Manager: E. G. Altouney*

User's Guide for REAP

EA-1551 User's Guide (RP1364-1); Part 1, $10.50; Part 2, $8.25

EPRI's residential energy analysis program (REAP), a computer program, provides a detailed mathematical model for determining residential space-conditioning energy requirements. Part 1 of this guide covers data input preparation for REAP. It describes the input variables, presents the input format, cites sources for the data, and suggests procedures for speeding data preparation tasks. It also provides sample program inputs and outputs and forms for use in preparing input data. Part 2 of the guide deals with the program structure. It provides insight into the algorithms used, discusses the different program elements, and gives background information that traces the evolution of the routines to their current forms. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: Edward Beardsworth*

Aggregate Elasticity of Energy Demand

EA-1559 Final Report (RP875); $3.50

A study was undertaken to develop consistent estimates of the 15-, 25-, and 35-year energy demand elasticities implicit in each of 16 detailed models of the energy sector. The comparison of results is descriptive; there was no attempt to produce a single best estimate of the demand elasticity. However, comprehensive models estimated statistically with historical data seem to produce larger aggregate elasticity estimates than other models. The contractor is Energy Modeling Forum. *EPRI Project Manager: S. C. Peck*

Energy Supply and Demand Properties From Engineering Process Models

EA-1568 Final Report (RP1055-1); $7.25

The usefulness of engineering process models (which primarily employ linear programming) in forecasting energy supply and demand was examined. The Integrated Industry Model, a model of several petrochemical industries and the electric utility sector, was used in the analysis. The utility sector model's ability to track historical and planned industry expansion was evaluated. The contractor is the University of Houston. *EPRI Project Managers: S. D. Braithwait and A. N. Halter*

NUCLEAR POWER

Seismic Piping Test and Analysis

NP-1505 Interim Report, Vols. 1–3 (RP964-2, -3, -4, -6); $16.00

This report presents the first-phase results of a dynamic testing and analysis program in which the 8-in-diam Indian Point-1 reactor feedwater pipeline is being subjected to various dynamic excitations under various kinds of restraint configurations. Volume 1 describes forced-vibration and snapback tests, as well as on-line data collection and management; Volume 2 discusses the development of on-line computer-based strain-response monitoring; and Volume 3 presents pretest analytic evaluations. The contractors are Anco Engineering, Inc., EDS Nuclear, Inc., and Philadelphia Electric Co. *EPRI Project Manager: H. T. Tang*

Prediction of Annular Liquid-Gas Flow With Entrainment: Cocurrent Vertical Pipe Flow With Gravity

NP-1521 Topical Report (RP1380-1); $4.50

A simplified semiempirical model for annular two-phase (gas-liquid) flow with liquid entrainment in a vertical pipe was developed. It improves on an earlier model by incorporating the effects of gravity. Model predictions were compared with data from tests using air-water, air-trichloroethane, and steam-water mixtures. The contractor is S. Levy, Inc. *EPRI Project Manager: K. H. Sun*

Thermal-Hydraulic Characteristics of a Combustion Engineering System 80 Steam Generator

NP-1528 Interim Report (S129-1); Vol. 1, $5.25; Vol. 2, $10.50

CALIPSOS, a three-dimensional flow distribution computer code, was used to analyze the steady-state thermal-hydraulic characteristics of a Combustion Engineering System 80 recirculating steam generator for full-, intermediate-, and low-power operation. Volume 1 presents the results, discusses the formulation of the CALIPSOS model, and defines the assumptions, transport correlations, and geometric dimensions pertinent to the model. Volume 2, an appendix, presents the thermal-hydraulic information contained in the CALIPSOS output for the C–E System 80 steam generator. Specific reference is made to overall performance data and to the dependent-variable fields that convey the modeled steam generator. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: D. A. Steininger*

Metallurgical Analysis of Rim Cracking in an LP Steam Turbine Disk

NP-1532 Final Report (RP1398-1); $8.25

The nature of in-service cracking in low-pressure turbine rotors in a PWR power plant was investigated through detailed magnetic particle inspections of disk rim samples, metallographic and fractographic examinations of cracked blade attachment steeples, and chemical analyses of the disk material. The cracking was predominantly intergranular in mode, and it developed by multiple crack initiation. It was concluded that the primary mechanism was a form of stress corrosion cracking. The contractor is Southwest Research Institute. *EPRI Project Manager: M. J. Kolar*

Defect Characterization by Acoustic Holography: Imaging in Field Environments

NP-1534 Final Report, Vol. 1 (RP605-1); $5.75

This volume describes the acoustic holography images obtained when American equipment was used in a field environment to characterize defects in thick-plate components. Results on both production and nonproduction components are included, along with descriptions of the equipment (which used optical reconstruction techniques) and test configurations. The contractors are COE Associates and Babcock & Wilcox Co. *EPRI Project Manager: G. J. Dau*

Technology Transfer Phase of Advanced Ultrasonic Nuclear Reactor Pressure Vessel Inspection System

NP-1535 Final Report (RP606-2); $7.25

This report describes the configuration and major components of a proposed manufacturing prototype of the advanced ultrasonic nuclear reactor pressure vessel inspection system. The development effort, including the evaluation and technology exchange phases, is summarized. The contractor is Sigma Industrial Systems, Inc. *EPRI Project Manager: K. E. Stahlkopf*

Pressure Boundary Technology: Progress in 1979

NP-1540-SR Special Report; $5.75

This report describes the progress of pressure boundary technology research toward its goal of improved nuclear plant reliability and availability through material characterization, flaw analysis, and fabrication and repair. The 1979 projects are reviewed and their interrelationships discussed. *EPRI Project Manager: T. U. Marston*

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