Load Management

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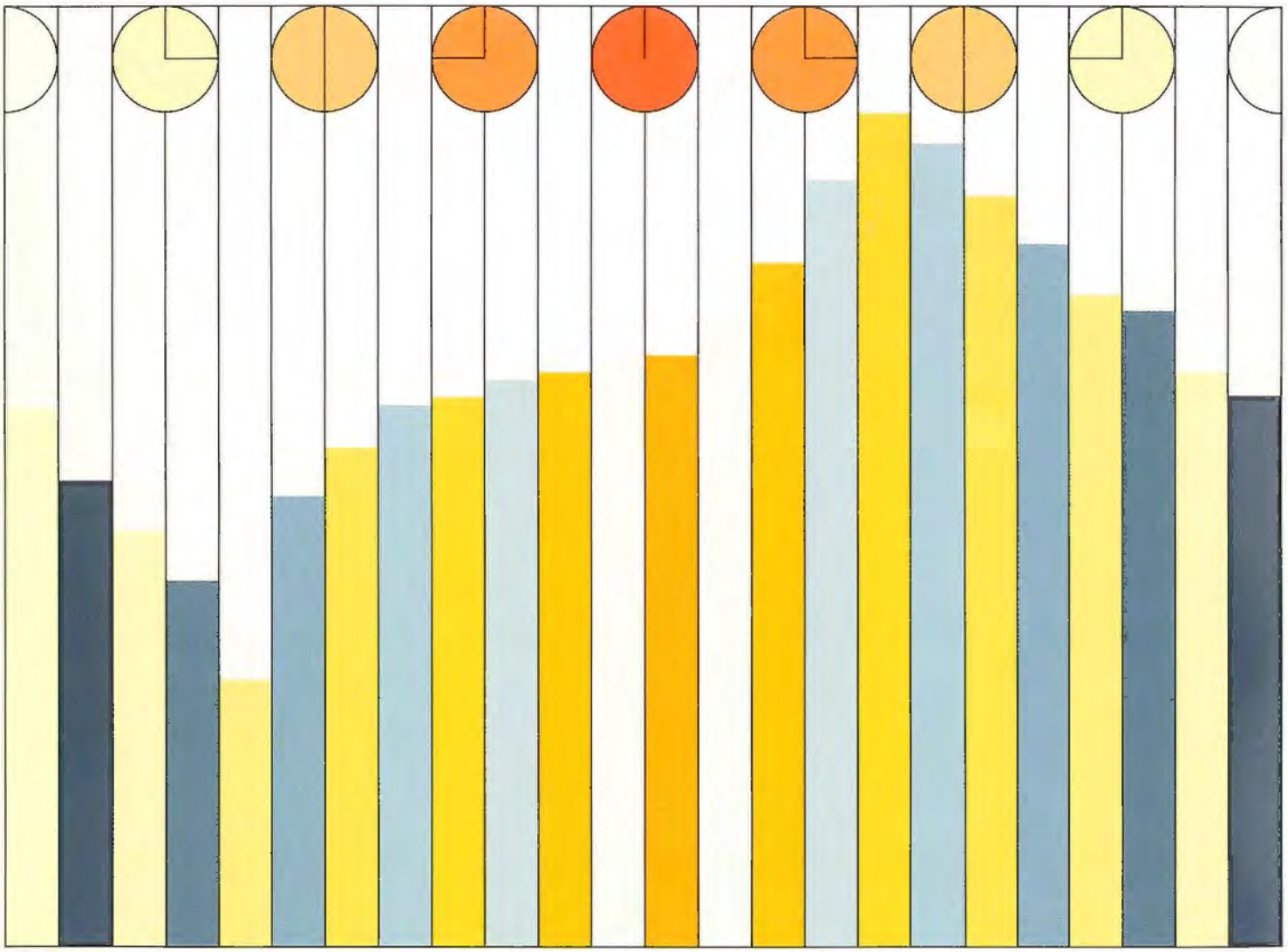

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Cover: Hour by hour, successive values of average electricity demand reveal a utility's total load for the day and its profile, the load curve. If we preserve the total load but flatten the curve, what are the implications?

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The Paradox of Load Management

Load management! What is it? Perhaps the most misunderstood term in our industry today. It is an utterly simplistic phrase, seriously misleading those who think they most thoroughly understand it. On the other hand, to those who really do understand it, it is a very complex subject indeed.

The problem stems from the fact that load management means different things to different people. Some consider pumped storage plants or peaking gas turbines to be forms of load management. I prefer to call these *supply management,* because they don't really change the revenue load. If we are truly to manage the revenue load, we must concentrate on residential and small commercial loads. As pointed out in this month's feature article, demand meter billing of industrial and large commercial accounts is already quite common and provides the incentive for those customers to control their own loads.

It is generally conceded today that demand meters are not practical for universal installation on residential loads. Nevertheless, management of this load category is practical either through a rate structure that encourages the customer to control his own load during peak periods or by the offer of a reduced rate in return for allowing the utility to control some portion of the load. The latter method is probably more efficient because service would be curtailed only when necessitated by system peak demand.

Difficulty with the definition of load management is compounded by failure to understand a closely associated term, *load factor.* For example, many spokesmen seek significant improvements in the efficiency of electric power systems by large

increases in load factor. This is the result of two misconceptions. One is the confusion between annual load factors, which average about 60%, and daily load factors, which average 80–85%. The other misconception is that a 100% load factor would be ideal.

Let's take these one at a time. No known or suggested type of load management is going to be aimed at changing annual load factor. One cannot run an air conditioner in December to cool a home in July! But daily load factor, even though quite high, can be improved. However, there is some point of diminishing returns. A system with a daily load factor during its peak season of, say, 82% might benefit enormously by load management up to a load factor of 90% or 92%. But further "improvement" could be illusory. It suggests that inefficient peak generating units would have to come into play more frequently as overall load gradually grows and requires more use of available plant capacity.

In sum, the paradoxical nature of load management is only in how it is understood. With more thorough and widespread knowledge of what it means and how it can be applied, load management will be seen for what it really is: a group of specifically useful tools for achieving an even better economic fit between reliable generating capacity and customer demand.

John J. Dougherty, Director
Electrical Systems Division

With all the talk lately about roots, it would be timely to find some such connection in or among the JOURNAL's features. It would also be sheer coincidence. But, this month, there it is: Even if not the single origin implied by *roots*, at least the separate *beginnings* of a concept, a practice, an institution, and a research discipline figure centrally in our four articles.

▪ **"Load Management"** (page 6) is the concept. Though not entirely new among electric utilities, it is still at the threshold, which is to say beginning, of widespread use. There is much interest—and not a little misunderstanding—about what load management portends for conserving either capital or operating cost (especially in fuel). Charles Rudasill, manager of technical assessment on EPRI's Planning Staff and formerly a longtime system planner for Virginia Electric and Power Co., contributed content and criticism to the article, which was written by Ralph Whitaker, the JOURNAL's feature editor. John Dougherty, director of EPRI's Electrical Systems Division, added comment of his own in this month's editorial.

▪ The practice is EPRI's—drawing on the expertise of member utilities and industry suppliers for temporary additions to its professional staff. The beginning was barely three months after EPRI opened its doors when a steam turbine expert from Westinghouse Electric Corp. became the first loaned employee. Since then more than 30 "loanees" have spent a year or longer at EPRI. JOURNAL staff writer Stan Terra talked with a sampling of loanees, past and present, and with a sampling of their EPRI colleagues, to gauge our success with **"Experts on Loan"** (page 12). In addition, the first reverse loanee, an EPRI staff member now on temporary assignment with a major utility, tells of his experience.

▪ The institution with a beginning is EPRI itself! Its formation signified a remarkable willingness of electric utilities to rise above their regional and organizational differences to cooperate in research that would help beat the energy crisis. But those early years were not entirely smooth, as Joseph Swidler, considered the founder of EPRI, told the JOURNAL's Barry Sulpor during a recent interview in his Washington, D.C., law office. As chairman of the Federal Power Commission under President Kennedy, Swidler was the first person to propose an organization such as EPRI. Now, in **"Joseph Swidler: The First Voice for EPRI"** (page 18), the EPRI Advisory Council member discusses what he originally envisioned for EPRI and what he hopes the future will bring.

▪ A research discipline that is just beginning is the subject of this month's technical feature. In reviewing the **"Realities of Ecological Modeling"** (page 49), ecologist **Robert Goldstein** predicts that this form of mathematical simulation, which "abounds in both potentialities and problems," in the next 10 years will become an increasingly important tool for investigating the environmental impact of human disturbances, including our energy technologies, on ecosystems. For example, what effect will a power plant cooling system have on the fish in a river or bay where the plant is to be built?

Goldstein combines a background in ecology with another in nuclear science. Involved in ecosystem analysis since joining EPRI's Environmental Assessment Department in 1975, he had been a theoretical ecologist at Oak Ridge National Laboratory since 1969. But he holds BS, MS, and PhD degrees in nuclear science and engineering from Columbia University, served as a physics instructor at Queens College in New York (where he had earlier earned a BA in liberal arts), and was on the staff at MIT's Lincoln Laboratory in Lexington, Massachusetts. Goldstein is a member of the Ecological Society of America, the British Ecological Society, and the American Association for the Advancement of Science.

Goldstein

"At 8 this morning all your electrical equipment came on at once."

That was the headline in an advertisement in the *Wall Street Journal* one day last winter.

"Too bad," the message went on to say, "you just boosted your power bill for the entire month."

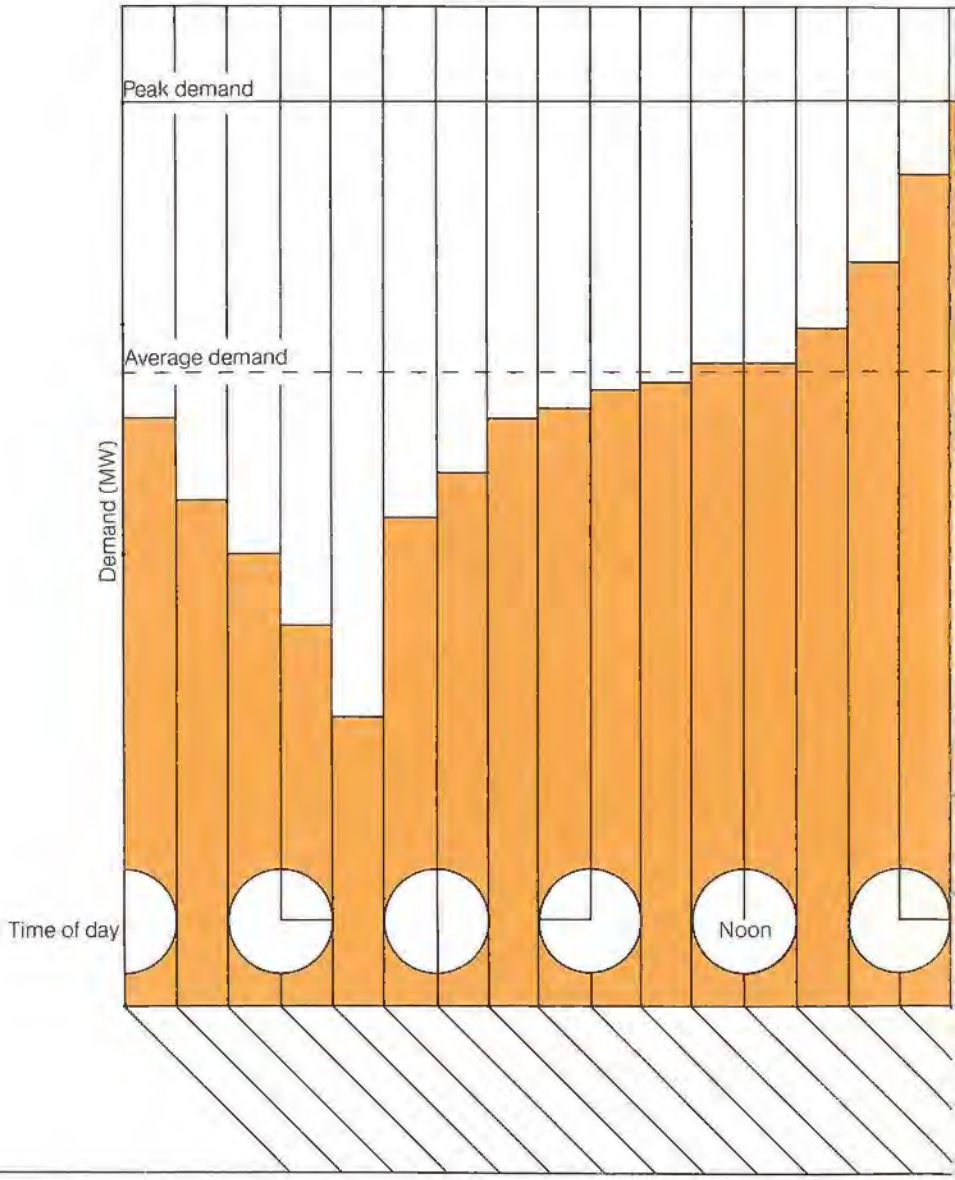
That ad was sure to be noticed by business people who pay for *all* their electricity at a unit rate determined by their highest half-hour demand on the utility system. The advertiser manufactured demand controllers, instruments that act on programmed instructions to shut off low-priority electrical equipment, when necessary, to keep the owner's total demand below a preset level.

Demand-based rates are one of several incentives for commercial and industrial electricity users to spread out their consumption over more hours of the day. And demand controllers are one of the many instruments that enable those large consumers to respond. Together, incentives and instruments are means of load management, shifting the time of electricity use.

LOAD MANAGEMENT

The techniques are rate incentives to the customers, coupled with instruments that can selectively switch off circuits and equipment. Big power users have known the benefits for years. But is it workable or beneficial for all customer classes?

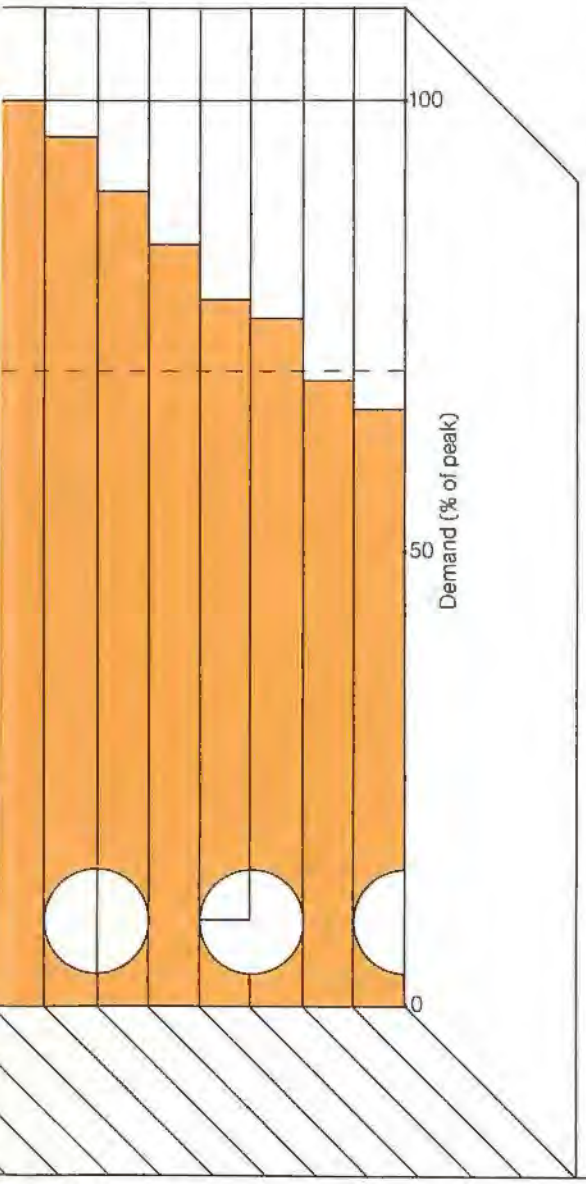
▫ An EPRI state-of-the-art feature



Who manages electric load?

But whose incentives and instruments are we talking about? In our example, the instrument is called a demand controller because it is something a consumer uses to budget his own rate of electricity use, or demand.

A utility can also install such instruments, or similar ones, that respond to time, to temperature, or to the state of other equipment. Or it can add instrumentation at its own stations, plus communication links for transmitting signals to actuate switches and relays, and thus control selected customer circuits or loads. All these techniques are part of load management. Using one approach, the utility provides the customer an economic incentive to manage his own load. Using the other, the utility manages the load and charges



Daily load curve traces the pattern of aggregate electricity demand throughout a utility service area. On this summer peak weekday, air conditioning raised afternoon loads well above morning values.

Each vertical bar is the average demand (MW) for an hour; thus the area under the curve is the day's total output (MWh). Drawing the full diagram—rather than just the upper part in which load fluctuates—shows that daily demand varies less widely than often supposed.

Load factor, the ratio of average to peak demand for the day, is the same as average demand (dashed line) when values are plotted in percent. "Valleys" below this level are equal in area (MWh) to the "peaks" above it.

a lower price for the service.

Scattered applications

Load management is widely but not uniformly practiced in the United States today. Incentives in the form of demand charges (peak load pricing) or time-of-day rates are common only among large commercial and industrial users. Here they are clearly justified because the volume of energy use is large and its cost readily calculable. In addition, the costs of special metering and accounting are low in proportion to the volume involved.

During the 1950s and 1960s, scale economies and technical advances in electric generation made load control by utilities unnecessary. Generally, instruments for such direct control have been limited to those in a few scattered experiments begun within the past two or three years. One early attempt at load management was The Detroit Edison Co.'s management of 200,000 electric water heaters. Some years ago, Detroit and other systems with many electric water heaters controlled those loads with timers; eventually changing load characteristics made the effort uneconomical. In 1968, however, Detroit reinstated the program, using radio control.

Another effort, involving large institutional power users, was interruptible power, which is furnished only by specific agreement and for a significant price consideration.

Between 1965 and 1975 the picture changed dramatically. Every index and component of electricity cost went up steadily, even sharply. Utility construction costs, the consumer price index, and fuel expense all rose by 250%. Utility output, of course, continued to grow, but marginal capacity became more costly than embedded capacity by as much as two to one.

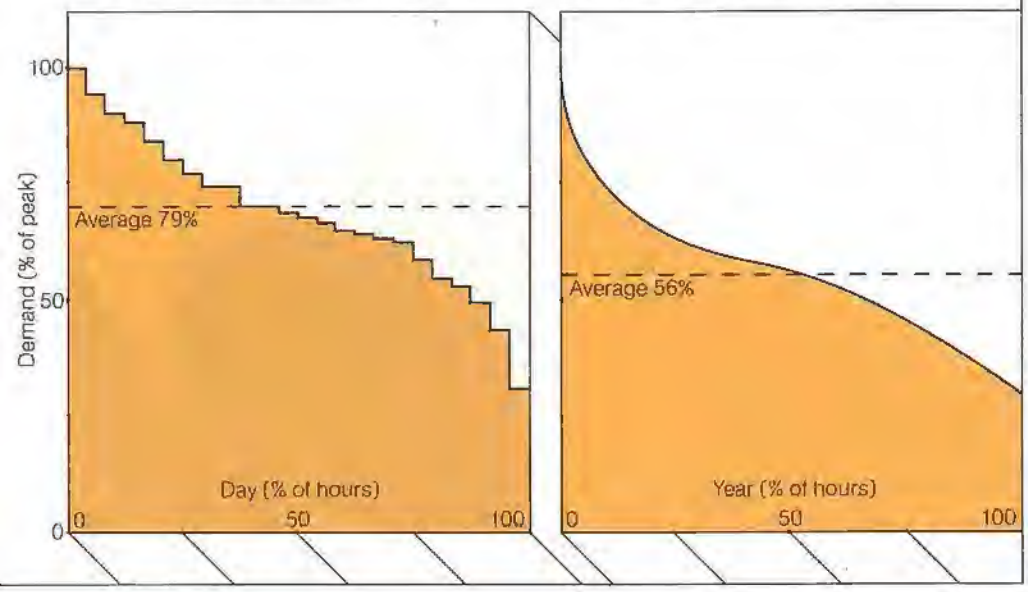
Why shift peak load?

All load management focuses on the shape of the load curve. Tracing out

Load duration curves portray the same information as load curves except for the time of demand. However, equal energy values above and below average are more clearly evident on load duration curves, as are the optimal proportions of total output to be generated by baseload, intermediate, and peaking units.

An annual load duration curve is smooth because it is plotted from 8760 hourly average demand values. Annual load factor is lower than most daily values because it compares the average of all hours with the single highest hour of the year.

Load management seeks to raise the daily load factor so that more output can be produced with the same generating capacity, without sacrificing system reliability.



the daily, weekly, or annual profile of instantaneous demand on a system, the load curve portrays electric utility service. This is because there is yet no universally feasible way to store energy in amounts useful to a utility. The load curve is the sales curve; it is also the production curve. The quick popular view is that peak load should be cut back—either by price incentive or by outright control—to make more consistent use of the most efficient generating units, thus saving both fuel and money in the immediate future.

A less dramatic view, and one more mindful of technical factors, is held by electric utilities. Aware that overall demand is rising year by year, they look to the peak-shaving action of load management mainly as a way to delay the need for new power plants. Spreading the load more evenly among existing generators today (and perhaps for a few tomorrows) is a way to conserve capital more than anything else—no small goal in today's economy if overall demand can continue to be met.

Straws in the wind

A good bit of conjecture and even disagreement attend the subject of load management, and for at least three reasons. One is the tremendous divergence in electricity costing and ratemaking theories among economists, engineers, marketers, regulators, and users. The second is that the foreseeable margins of savings are small, perhaps as little as 1%, leaving no room for error in an entirely new operating and economic experience. The third reason is that load management seems to mean a basic change in the philosophy of service, calling for the customer's electricity demand to be shaped to fit the utility's generating capacity rather than the other way around.

In sum, we are in a time when load management is popular, but there are conflicting reactions. Some people see it as an immediate panacea: rate relief for the small consumer, fuel conservation, firm control of big business, and a clear pattern for new ways of societal life. Others see it as impractical: individuals won't change and economic institutions shouldn't be forced to. Meanwhile, there are these straws in the wind:

- Several European countries, as well as New Zealand, Australia, and South Africa, have practiced load management for years.
- The FEA is evaluating load management by sponsoring a number of demonstration programs featuring peak load pricing.
- EPRI and ERDA are cooperating in a $7 million test of two-way communication and control hardware for load management.
- EPRI and the Edison Electric Institute (EEI) are well into the second year of a rate design study, including time-of-use pricing, requested by the National Association of Regulatory Utility Commissioners (NARUC).
- In at least four instances, state regulatory bodies have directed electric utilities to extend time-of-use rates to smaller commercial and industrial customers.
- NARUC's Executive Committee has recommended that the Federal Communications Commission set aside two channels, 940 and 952 MHz, for electric utility load control by radio.
- EEI's System Planning Committee has just completed the second phase of its study of load management effects on utility planning and operations.
- Most important, through today's research, development, and demonstration programs we are replacing conjecture with firsthand knowledge of the effects of load management.

Load factor points the way

Differences between daily and annual load curves are important in understanding the role and potential of load management. Both types of curves are compared in terms of load factor: the ratio of average demand to peak de-

WHAT WE MEAN WHEN WE SAY "LOAD MANAGEMENT"

Ideas for influencing or controlling load curves have cascaded forth in recent years from utilities, regulators, users, and manufacturers. Load management has become a buzzword, encompassing so many things that it is hard to use the term concisely.

What's worse, load management opportunities are impossible to assess economically if they are allowed to include measures or equipment outside the utility's control or too far into the future to permit reasonable certainty.

Some definitions are in order, and a more specific viewpoint of load management is necessary.

Load management deals with customer loads—by category or in total—as they exist today, seen from the utility's side of the electric meter.

Load management covers a user's own efforts to shift or reduce his pattern of electricity use when those efforts are stimulated by utility rate incentives. It includes the use of instruments, from clock-timed relays to entire computer systems, that restrict energy use (demand) at traditional peak hours or weather-caused peak periods. Energy storage devices that a consumer may install are part of his own load management, and so are shifts in his operating routine that have the same effect without instruments.

Load management does not deal with utility system interconnections or with utility energy storage. These are modes of supply management. Neither has any effect on customer load; instead, both influence the utility's pattern of electricity generation. Supply management closely parallels load management in that it makes possible the more efficient and economical use of generation capacity.

Energy management is an umbrella term, often used to cover load management, supply management, and even conservation. It thus connotes the responsibility that everyone has to make the most effective, least wasteful use of energy. For many utilities, conservation is an intensive educational effort to influence where and how—and how much—electricity will be used in structures and processes of the future. The objective is to level loads, rather than to reduce them outright. Energy conservation measures designed for tomorrow will thus serve the same purpose that is sought with load management today.

mand during a selected period.

Annual load factors for U.S. utilities range from less than 50% to almost 80%, with a national average of 61%. Daily load factors, on the other hand, range from about 75% to above 90%. For either type, the range is a function of geographic and weather patterns and of the distribution of electric service between the extremes of residential and heavy industrial customers.

For a given system, the daily load factor does not vary markedly from one week to the next because it is indexed to itself: a ratio of two values from the same day.

Annual load factor, furthermore, will always be a lower value because its numerator is an average of all daily average demand values during the year, but its denominator is the highest peak demand value recorded during the year. Annual load factor, therefore, is not useful in gauging the potential for load management benefits on a system. This is often overlooked or misunderstood when annual load factors are cited to characterize systems.

To assess the potential for load shifting, it is necessary to review daily load factors during the season of highest peak demand. The lower the load factor, the greater the load management potential. At seasons of the year when peaks are lower, there is capability for load shifting, but it may not be needed if the load factor is already high, indicating a generally good distribution of generating capacity with emphasis on the efficient units.

Capacity is tailored to load

A utility must have at least as much generating capacity as its foreseeable peak demand—plus carefully calculated reserves in various categories to cover contingencies and permit orderly maintenance.

Generating capacity is a mix of plants with different cost efficiencies at different generating levels, depending on plant type, fuel, size, age, and so on. To a great extent this mix is deliberate; for example, large nuclear-, coal-, oil-, and gas-fueled plants are the most expensive to build (measured in capital cost per kilowatt), but they are also the most efficient in converting raw fuel energy into electricity, and their fuel has been the cheapest historically. However, they cannot be started and stopped on a daily basis; in fact, they cannot even "cycle" quickly among generating levels and are truly economical only when running day and night at the same output. So they—at least the biggest, newest ones—are run in just that fashion and are called baseload generators.

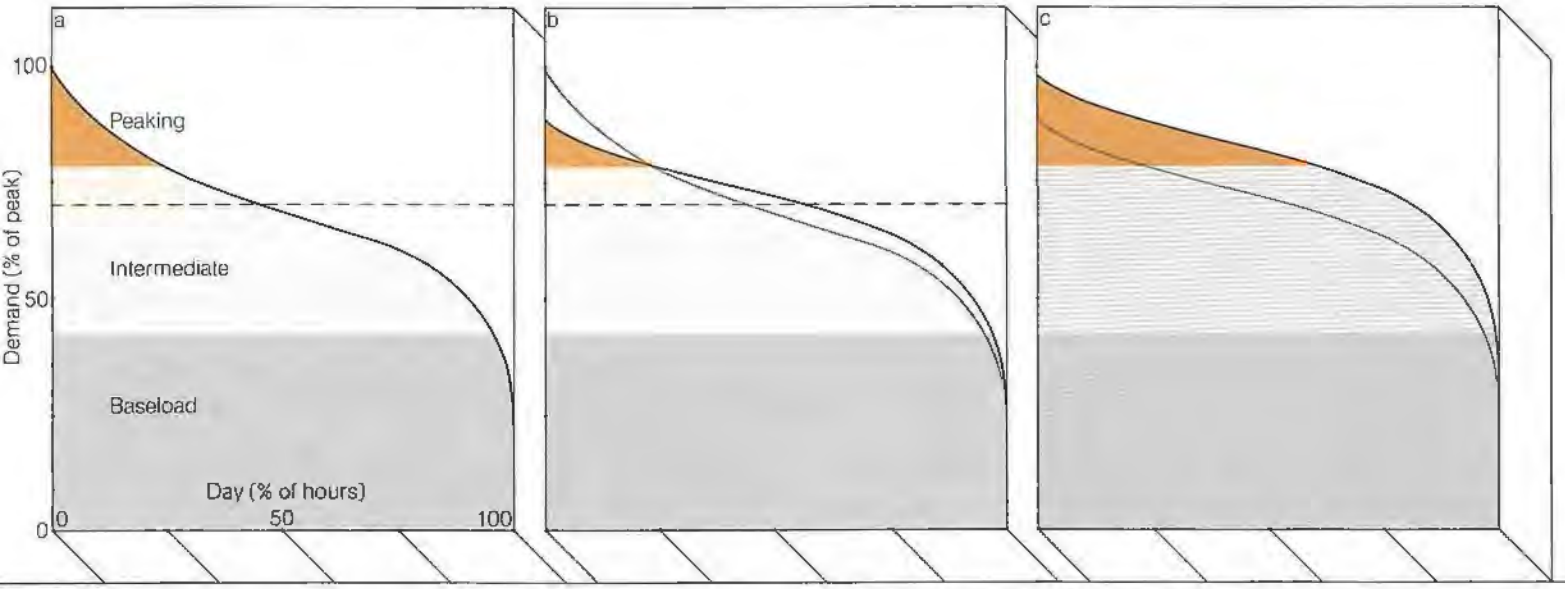
Older, smaller plants are cut in for what is known as intermediate or cycling duty, the daily periods of many hours during which most of us function and therefore create demand for either personal or business reasons. This electricity is more costly to produce because the generator must operate at least some of the time above or below its own most efficient level and its age and size probably mean a lower basic efficiency.

A group of specialized, quick-starting generators—frequently oil-fueled gas turbines—are available to meet the high, short-duration peaks of demand.

Load management and the progressive effects of system growth are shown in simplified form by these four daily load duration curves.
Unmanaged load (a) has an appreciable slope, a small proportion of overall output being concentrated to create a relatively short period of peak demand and a requirement for peak generating capacity to fill it.

Managed load (b) involves the same total energy output, but the load is distributed more evenly. The unchanged average demand is a higher proportion of the reduced peak; in other words, the load factor is higher. Capacity cost per kWh is unchanged, but fuel and operating cost is down because there is less use of peaking units. Reliability is up because of greater idle capacity.

Managed load with growth (c), after time has passed, has the same load factor as (b), but the peak demand is now just below the original, unmanaged value, and reliability is now again the same as (a). Capacity cost is less because an unchanged capacity mix is producing more energy at the high load factor. But peaking units are running more than in the unmanaged case, and high fuel and operating cost offsets much of the capital cost saving.



These units are small, and because they can be built as standard models instead of customized, they are relatively cheap in capital cost. These "peakers" provide fast delivery to meet fairly short-notice increases in system peak demand.

The peak generator is optimized for economical ownership because most of the hours of the day, year, or lifetime it is simply owned and not operated. Although its fuel and operating costs, including maintenance, on an hourly basis may be very high, its total costs are not too different from those of other units.

Capacity mix saves money

Because an electric load must be matched by an equal output, or supply, the combination of generating units and power plants on-line must rise and fall with demand. For a period of high load factor, the large, efficient generating units are used a greater portion of the time. This is the basis for any immediate or short-range operating savings that are possible with load management, mostly in the cost of fuel.

Capital cost savings become possible with the passage of time insofar as peak loads can be shifted, load factors increased, reserve margins maintained, and some net new load accommodated that would otherwise have required new generating capacity. But as capital is conserved by this deferral of capacity, the earlier fuel and operating savings disappear. Because the net new load is spread out to preserve a high load factor, intermediate and peaking generators are run for longer intervals, despite their higher fuel and other operating costs.

Seen in this light, load management is more of a long-term proposition, requiring 20 or 30 years' time in which to gradually optimize generating mix for a higher load factor, that is, with a higher proportion of efficient, economical baseload generators.

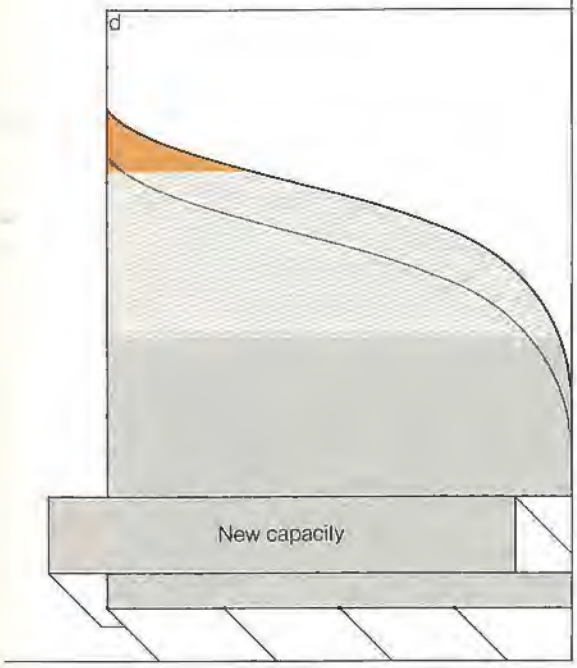
Savings may be slight

The first phase of study by the EEI System Planning Committee reveals that small savings are to be experienced from load management, at least in the context of the predominantly oil-fired utility system investigated under five alternative schemes.

Actual 1970–1973 data provided a base case, particularly on the mix of installed capacity. Five other managed scenarios were modeled, all of them preserving the same capacity mix (though employing it differently) and reliability. All the scenarios achieved an annual load factor higher than the original, 66.7%.

In terms of overall costs, the best alternative achieved an annual load factor of 74.8% and saved 0.3 mill/kWh (from 32.6 to 32.3), or 1%. The same alternative produced only 8.5% more output, 69,440 $\times$ 10^6 kWh versus 64,000 $\times$ 10^6 kWh, suggesting that new capacity could not be long deferred without sacrificing reserve

Managed load with new capacity (d), after still more time, accommodates a still higher overall load. But the capacity mix is now being optimized for the new load factor by adding baseload units, which take over from less efficient intermediate and peaking units to cut fuel and operating cost again.



margin and system reliability. Even this modest increase in output required a 3.3% cut in peak demand (from 10,989 kW to 10,624 kW).

This extreme regimen had the same overall seasonal (and even weekly) variations as the base case, but all *daily* loads were completely leveled (100% load factor). Two other alternatives were even more extreme, one leveled all individual weeks and the other leveled the entire year. But neither produced operating cost savings of as much as 0.3 mill/kWh, and both required marked increases in reserve capacity to preserve the same reliability.

What's the outlook?

Load management is likely to become commonplace, though not solely for the intended reason of shifting peak demand to save operating or capital costs. It will also come about as a means to deal with at least two other factors: First, increasing recognition that the cost of electric service varies with the time of day as well as with the season of the year. More important, methods are being developed—and agreed upon—for calculating those costs and building equitable rates on them. This is the result of regulatory concern on behalf of ratepayers faced with steeply rising charges in recent years. The joint EPRI–EEI research into time-of-use pricing stemmed from a request by NARUC.

Foreseeably, utility costs will continue to rise: labor, materials, fuel, interest rates—all are heavily represented in electricity cost. But those higher costs will be built into time-based rates according to the levels of system demand that require them to be incurred. Inevitably, such time-of-use pricing will cause peaks to shift, load factors to rise somewhat, and the benefits of load management to be experienced.

The effects of energy conservation efforts are not so clear-cut. Where the consumer's motivation is simply to use less total energy, his contribution to peak demand falls, but so does his contribution to total load, and the load factor is not improved. It may be reduced. But where the consumer's motivation is to save money as well, his own budgeting mechanisms—such as the controller to take advantage of demand-based rates or a timer to take advantage of off-peak rates—will accentuate the demand shift.

Since the electric utility industry began, the name of the game has been supply management: the best mix of generating facilities, pooling, and storage, to match an independent load curve. Now, just when the tools for this task are finely honed, it is becoming more widely apparent how the utility's own cost and price patterns exert influence on that load curve. Seen in this light, load management is an element of supply management, a growing part of a traditional task.

CONSERVATION AND LOAD LEVELING

The biggest group of peak electric loads that can be shifted are in the residential category: the water, space heating, and air conditioning loads. Today they can be managed only by controllers that cycle them off for brief periods (on a timed or rotating basis) to cut coincident loads and thus the system peak.

Tomorrow these loads can be leveled by energy-conserving housing design. Electric utility efforts to educate consumers, architects, and builders on energy conservation include the following areas of concern:

- Siting (orientation and exposure)
- Plantings
- Roof pitch, color, and overhang
- Attic ventilation
- Window size
- Double glazing of windows
- Wall cavity thickness
- Insulation and weatherstripping
- Caulking
- Solar heating and cooling
- Thermal storage (heat or coolness)
- Heat pump
- Microwave oven
- Fluorescent lighting
- Location of water heater, furnace, and clothes dryer

Careful planning of these items will reduce the peak electricity use of an all-electric home from today's 8–10 kW to 3–4 kW. Call it energy management, or call it conservation. Either way, if you multiply this reduction by all the houses in your town, you will find it amounts to quite a cut in the peak that now builds up on a blustery January day or a hot August afternoon.

Experts on Loan

As early as its beginning, EPRI has tapped the talent of its member utilities and of industry suppliers to help keep its R&D programs on track. A sampling of these experts tell of their experience on temporary assignment at EPRI.

Among the early steps taken by EPRI to stay on its intended path was to bring on staff a variety of experts on loan from member utilities and supplier companies whose practical viewpoints in dealing with real problems have helped focus the Institute's research efforts on the real world.

In March 1974, just six months after EPRI opened its doors and with three loanees from Westinghouse Electric Corp. already in residence, President Chauncey Starr sent a memo urging the chief executives of the Institute's member utilities "to nominate one or two of your best technical personnel as candidates to work at EPRI for a year on a loan arrangement."

David Saxe, director of administration, who worked closely with Starr and EPRI's personnel officials in setting up the loaned employees program, says that it became apparent that "part of our staff would have to be temporary in order for us to have a continuous infusion of new minds with new ideas for planning, evaluating, and guiding our work."

At first the response came mostly from suppliers, who at the time were in a stronger economic position than utilities to spare a key person for a year. (Utility companies were then in an economic squeeze from the Middle East oil embargo, as well as from inflation.) The period of residence at EPRI is normally a year, but it may be extended, with the person receiving the same or comparable salary and benefits being paid by the permanent employer.

Acting Personnel Manager Richard Ensminger stresses that "our policy is not to encourage loanees to join our staff permanently," so utilities need not worry about EPRI pirating some of their best people. "Loanees grow professionally and make contacts working at EPRI that benefit their careers and their companies," Ensminger points out.

More than 30 people, mostly engineers from utilities and suppliers, have taken part in the program since Starr sent out his appeal three years ago. About 18 are currently on the staff.

René Malès, with 20 years' service at Commonwealth Edison Co. in Chicago, most recently as manager of general service and corporate economist, came to EPRI on loan for 18 months in early 1976 to head the Energy Analysis and Environment Division. Malès directs a staff of 30 economists, mathematicians, and environmental scientists engaged in studies on energy demand, supply, and conservation, systems modeling, and environmental assessment. The utility rate design study also is within the division's scope.

Malès

Malès, whose stay at EPRI has been extended a year, says he has seen the research efforts of his division aimed "more toward direct application to utility industry problems and to choosing R&D technology priorities at EPRI." The industry has looked to his group for a research strategy to deal with such concerns as future electricity demand, fuel supplies, and environmental impact of electricity generation and transmission. "Utilities

feel constrained by environmental standards," he notes, "and have come to us for scientific research that will throw light on the issues and bring more understanding to the shaping of future standards."

Malès observes that "many R&D failures are traceable to the misconception that the laboratory setting is fully transferable to the real world." Having utility people keep a hand in the research, he says, helps EPRI avoid such failures.

An earlier concern among the division's staff that concentration on applied research would exclude work on state-of-the-art studies has been proved unwarranted, Malès notes. Experience has shown that both pursuits are compatible at EPRI, and he cites as an example pioneering work in adapting national energy models for utility industry application and investigation of the health effects of fossil-fueled power plant emissions.

Malès feels he is getting "a broader, deeper understanding of the value of R&D technology development and of its environmental and economic aspects." He has gained "new and clearer insights of the Washington regulatory scene" as well. And when he returns to Commonwealth Edison, says Malès, he will take with him "a less provincial view."

Charles Rudasill, a 28-year veteran with Virginia Electric and Power Co. and a pragmatic utility professional, was brought in on loan to set up a technical assessment group as part of EPRI's planning staff. He and a small staff of analysts, with backgrounds from the utility, supplier, and R&D fields, evaluate programs and projects to help keep them responsive to utility needs.

"Our job is to look at EPRI research as a utility planner would, using standard utility methods, to make sure the results will have practical value," says Rudasill, who is director of transmission planning at Vepco. The group's work is aimed at guiding the Institute in setting "rational, consistent priorities in line with utility needs." And Rudasill stresses the importance of tight budget controls. The staff works closely with program and project managers, at times attends discussions with research contractors about details of final reports, and reviews final report drafts of selected projects.

A technical assessment guide has been drafted by the staff, incorporating viewpoints expressed by utility representatives at EPRI-sponsored workshops on the subject. Larry Olah, a loanee from Westinghouse and a member of Rudasill's staff who helped put together the guide, says that "to assess R&D technology, you have to consider such factors as energy mix, anticipated demand, required capacity, and various technological options, making sure all costs are included and that your figures are reasonable, relative, and consistently based."

Rudasill

Among projects being worked on by Rudasill's group are studies of dispersed generation, energy storage, and reliability, using models of six hypothetical utility systems.

Rudasill says he is pleased that his colleagues on EPRI's regular staff often call him or drop by his office to ask what the utility viewpoint is on a given issue. An area where he believes EPRI particularly needs guidance is in learning the criteria that utilities use as a basis for their investment decisions. He adds, however, that there is an advantage in EPRI staff people "not having a utility cast of mind. Their approach to problems from the R&D angle can result in innovative solutions." Rudasill feels he has "helped open many eyes at EPRI about utility operations and been an influence in guiding the direction of research in some cases and in shaping long-range planning."

Plant reliability is a principal concern of utility operators, a concern that is getting considerable attention at EPRI. One of the most seasoned experts in the various aspects of fossil fuel combustion joined EPRI on long-term loan in 1974 and now heads the program in fossil plant performance and reliability. Donald Anson directed combustion research and chemical engineering, among other responsibilities, for the British Central Electricity Generating Board (CEGB) before coming to EPRI. He also worked closely with CEGB's five regional scientific service groups in England and Wales that aid local power plants in solving operational problems.

Anson sees plant reliability as "an area where EPRI can make a significant contribution to the utility industry." He foresees the potential for "economies on the order of $10–$15 billion over the next 10–15 years" as a result of improved reliability. "The more reliable the system is, the less need you have for costly standby equipment," he says.

Anson points to the "heterogeneity" of the U.S. utility industry, with utilities varying in size from a single plant to a giant TVA, as a particular problem of the American scene. "Plants need to be large enough to use modern technology efficiently," he says, "and a greater degree of standardization would make for more efficient development."

Based on a few inherited projects on steam plant reliability that were initiated by loanees from supplier companies, Anson set up the Fossil Plant Performance

and Reliability Program. "It has been difficult to attract people from the utility industry with the kind of engineering, design, and R&D experience needed for this work," he comments. "They are key people in their own utilities and usually can't be spared."

Soon after arriving Anson gave a presentation to the staff of the Fossil Fuel and Advanced Systems Division on advanced combined-cycle systems. "I believe the message got across," he says, "that the EPRI commitment to coal conversion systems had to relate to both the nature of future demand and the structure of the utility industry." Anson drafted a proposal to study fluidized-bed combustion technology at a more realistic scale than had previously been possible. This led to a $2.5 million, 3-year project for engineering-scale experiments and prompted broader participation by the boiler vendors in this technology.

Anson has assisted in long-range planning and drafted an analysis of programs in the Fossil Fuel and Advanced Systems Division that has helped subsequent program planning.

The program analysis was done for George Hill, director of the Fossil Fuel Power Plants Department, who says Anson "represents the ultimate" as a contributor to EPRI's work. "He has won the confidence and respect of EEI's Prime Mover Committee, which has enabled us to move ahead in the area of performance and reliability," Hill notes.

Half the current loaned employees are working on nuclear power projects. Among them is Joseph Prestele, with Consolidated Edison Co. of New York, Inc., since 1949 and involved in nuclear power reactor design and operation for the past 20 years. Prestele was general superintendent of Con Edison's first Indian Point nuclear power plant and later managed Con Edison's Nuclear Power Generation Department, among other duties, before coming to EPRI in 1974 on a long-term loan to direct the Nuclear Power Division's Codes, Standards, and Reliability Program. Prestele recently was named acting assistant director of the Nuclear Engineering and Operations Department.

Larry Minnick, department director who also heads the LMFBR project, notes that Prestele has brought to EPRI "an intimate understanding of reactor operations and of the engineering and licensing connected with nuclear power generation."

Anson

Prestele reflects that at the time he arrived at EPRI "there was clearly a need for people with practical experience in nuclear power plant design and operation." He describes his influence as that of providing "long-standing familiarity with the people and procedures in the nuclear field in and out of government and helping move ahead more expeditiously" the projects he's been involved in at EPRI. Prestele believes he has helped in achieving the degree of cooperation from EEI that EPRI has enjoyed in the nuclear reliability data systems program. He adds that insights he is getting at EPRI will likewise be useful when he returns to Con Edison.

Another nuclear power specialist and colleague of Prestele's from Con Edison is Jack Haugh, who was among the first to join the LMFBR design project when he came to EPRI on loan in the fall of 1975 for the 30 months of the team effort. With Con Edison since 1970, Haugh was a senior engineer whose work centered on licensing activities for the Indian Point No. 1 nuclear power plant.

Haugh, who says his work at EPRI has drawn directly on his experience at Con Edison, has been reviewing contractor designs from the viewpoint of safety, licensability, and maintainability. He has been directing his attention to fission and corrosion product behavior in the primary circuits of LMFBRs and their implications for realistic shielding and maintenance. Haugh has also been active in developing an industry standard for an LMFBR site suitability source term.

Minnick notes that Haugh brings to the LMFBR program "valuable understanding of the details of reactor design, licensing, and regulation."

Haugh stresses that "since the PLBR is being designed to tie into a utility grid, it is crucial that the industry's needs and experience be factored into the design." And he notes that "the utility viewpoint has been part of the program from the beginning," influencing decisions on such questions as: What should the plant megawatt output rating be? Should there be sodium reheat? What limits should be placed on the reactor outlet temperature? Says Haugh, "Our aim is to design a safe, reliable, maintainable LMFBR plant, and our approach is conservative. The biggest is not necessarily the best." Haugh feels he is getting valuable experience through his involvement in the design stages of an LMFBR and that he will take back to Con Edison "a greater data base for making decisions about the LMFBR."

In his 20 years with Westinghouse, physicist Robert Breen has gained a variety of experience in nuclear reactor sys-

tems, including the LMFBR, in business planning, marketing, and public affairs. Breen came to EPRI in 1975 to extend his experience "to the engineering aspects of reactors and to become familiar with utility operations and problems." Among other assignments, he is managing a project that is exploring alternative emergency core cooling systems.

Breen has drawn on one area of his Westinghouse experience—briefing members of Congress on the relative merits of nuclear power, especially of the LMFBR—in describing to EPRI's nuclear task forces and advisory committees technical information in a way that can be understood and that shows its relevance to utility needs.

Prestele

Breen says he has also served as "a bridge between my colleagues at Westinghouse and the EPRI staff to help in exchange of information and in clearing up any misunderstandings that may arise." Breen makes it clear that "while I'm here, my responsibility is to EPRI, not Westinghouse."

Walter Loewenstein, director of the Nuclear Safety and Analysis Department where Breen is assigned, says, "Bob Breen has versatility and depth in various technical areas and in overall program planning, where he has taken a global view in aiding our efforts to develop program direction, especially in light water reactor system technology." Adds Loewenstein, "We jumped at a chance to extend his stay another year. He's a winner by any measure."

The two engineers working on overhead lines research are both on loan and the program manager they report to is a former loanee. Frank Young, who was on loan from Westinghouse in 1974 and now manages EPRI's overhead lines research, says he is "ecstatic" over the work being done by Kenneth Griffing of Southern California Edison and Lennart Svensson of the Swedish State Power Board (SSPB). Young notes that Griffing is chairman of the IEEE working group on subconductor oscillation and "is highly regarded in the industry." Young relates that after reading data given in an EPRI research report on compact lines, Griffing recognized more investigation was needed on the effects of wind on transmission lines. Young considers this "a valuable observation." Griffing has drawn up a proposal for an EPRI research project on the nature of wind gusting and its effects on transmission lines. Svensson, says Young, "is a very competent engineer, has been adept at drafting projects, and is particularly good in budgeting and scheduling."

Griffing, who has worked on EPRI projects relating to conductor motion, subconductor oscillation, compact lines, and on project UHV experiments at Pittsfield, Massachusetts, says he reviews research reports with a utility engineer's eye "to see how useful the information will be for the engineer on the line who would have to apply it. Is it clear? Is it complete?" Griffing was a supervising engineer involved in the design of transmission lines at Southern California Edison and has supplied Young with the utility engineer's viewpoint and concerns. He has assisted in evaluating the usefulness of proposals and in long-range planning and setting of research priorities.

SSPB, Sweden's largest power producer, supplies about 45% of the country's electric power. Sweden was the first country in the world to operate a commercial dc system and the first to energize a 400-kV ac system. Svensson has brought to EPRI valuable experience gained at the SSPB (with whom EPRI has an agreement for the exchange of information and personnel) and has applied this experience to research in such areas as dc field strength instrumentation, corona losses, radio interference, and insulation.

Breen

Svensson points out that early consideration was given in Sweden to the importance of limiting short-circuit currents and to the need for designing the power

system to handle these currents. He notes that it was decided to limit short-circuit currents and that the Swedish power network is being modified accordingly. Svensson adds that the issue of environmental effects from high-voltage transmission lines is also being given serious attention in Sweden, as in the U.S. He feels that there is more attention given in Sweden than in the U.S., however, to international standards for equipment.

Svensson

The first in the flow of loaned experts came to EPRI in November 1973, just two months after the Institute moved into its Palo Alto headquarters. George Silvestri, an engineer with Westinghouse's steam turbine division near Philadelphia, recalls that the Middle East oil embargo occurred during his year at EPRI and his early months were spent reviewing questions and ideas coming in from concerned citizens, university researchers, and industry and utility people. Working with Vance Cooper on programs to improve steam power plants, Silvestri became involved in a number of projects dealing with such matters as ash fouling and slagging, corrosion and deposits from combustion gases, water induction in turbines, and a phase change cooling system for dry cooling, the latter a project he is still connected with as a Westinghouse turbine consultant.

Silvestri says that while at EPRI his experience and contacts in industry enabled him to call on his industry associates to get the current status of a given technology. As an industry engineer, he says, his interests were mainly in immediate problems and plant reliability. He notes with satisfaction that EPRI is giving more emphasis to short-range issues and reliability studies. Silvestri believes that his experience at EPRI "helped sharpen my technical judgement," and he recommends it "to anyone as a challenging learning experience and a chance to contribute."

Vance Cooper, now manager of the Power Generation Program in Advanced Fossil Power Systems, says, "We valued George Silvestri for his theoretical knowledge of thermodynamics and his practical experience with turbomachinery." He adds that Silvestri "contributed much in identifying the problems that often occur in turbines." Cooper further notes that Silvestri "led the first workshop with industry representatives to identify areas of potential improvement in steam power plant equipment."

Another former loanee, Harold Lurie, director of research and development at New England Electric System in Westborough, Massachusetts, found his experience at EPRI "a bit frustrating." Lurie feels that his 6½-month tenure as acting director of the Advanced Systems Department was too brief to be effective. But he makes clear that he enjoyed his staff contacts and gained valuable understanding of EPRI's operations. His "missionary work," like Silvestri's, helped EPRI "to see the importance of R&D in plant reliability, using present technology."

Lurie says that while he was at EPRI he had a "good and continuing" relationship with Richard Balzhiser, director of the Fossil Fuel and Advanced Systems Division. He adds that since he was interested in all of EPRI's operations, he feels that "other members of EPRI's top management could have gained additional perspective" by interviewing him at the end of his stay. He thinks EPRI could gain valuable information from follow-up "debriefings" of all loanees, especially after they've returned to their home companies and had time to reflect and evaluate.

Yu

Fritz Kalhammer, a program manager in advanced systems when Lurie was at EPRI and now director of the Energy Management and Utilization Technology Department, says, "Harold made a positive contribution in trying to establish research program priorities by analyzing industry needs and setting specific objectives." Kalhammer adds that he has "lots of respect for Lurie's observations, which

were usually astute," and that Lurie brings "a different intellectual thrust to the utility R&D community, where he is considered somewhat of a maverick." Lurie was a professor of engineering science and associate dean of the graduate school at California Institute of Technology before entering the utility industry.

Lurie, an original member of EPRI's Research Advisory Committee, feels that RAC would be more effective in setting research policy and priorities if its utility representatives had more time to devote to it. He suggests that a member of RAC work full-time with EPRI's planning staff on a loan basis, similar to the loaned employee arrangement, for closer liaison between RAC and EPRI in dealing with questions of research policy.

Lurie says that when he arrived in October 1974, "there were few people on the staff with utility experience and EPRI then had little understanding of utility problems." Lurie also found a "growing bureaucracy" at EPRI and says he has already received "stacks of paper" in connection with an EPRI task force he recently joined.

Kalhammer shares Lurie's concern over EPRI's growing bureaucracy, noting that "the bureaucratic overburden makes the work process cumbersome and takes staff time away from vital planning and project management activities." On this point, Rudasill remarks, "EPRI's crises are mostly paper-shuffle crises."

After three years the loaned talent is now moving in the other direction as well. Oliver Yu, a member of Rudasill's technical assessment group, began an 11-month on-loan assignment in February with Commonwealth Edison Co. in Chicago. Yu, an operations research specialist, is working in Commonwealth Edison's Systems Planning Department, developing models to calculate production costs of power generation and for long-range planning of generation expansion. He is also involved in reassessing the generation reliability requirements suitable for Commonwealth Edison's long-range planning.

Yu feels he can make a contribution to the large Chicago utility with his expertise in probability statistics and system analysis and by virtue of the fresh viewpoint he brings as an outsider. In turn, Yu says he is learning about the problems "peculiar to a large urban utility," and was interested in finding that Commonwealth Edison works closely with city government in planning.

Yu says that his hosts at Commonwealth Edison "have accepted me as one of them, have been open in communication, and accommodating in sharing information." They had a clear notion of what his contribution could be and "quickly lined up specific tasks for me to work on," he says. And Yu notes that he will be teaching a 10-week course in operations research this fall as part of Commonwealth Edison's in-house education program. The course, which Yu has taught at two universities in California, will be open to management and technical staff members.

David Saxe says he is "enthusiastic about the results of the loaned employee program so far." And although he would like to see more utility and supplier loanees come to EPRI, he recognizes that the utilities in particular "just don't have a surplus of technical people to spare for a year. Despite this," says Saxe, "their cooperation in sending the people they have has been gratifying. And the contributions these highly competent professionals have made by working on utility problems as temporary staff at EPRI will benefit the industry as a whole."

Joseph Swidler: The First Voice for EPRI

Joseph C. Swidler, the man who envisioned the enormous benefits to be reaped from a united electric utility industry research program, provides some interesting background on why EPRI was formed and where he hopes the organization will be heading.

▫ An EPRI Interview

"I am convinced, and many industry leaders to whom I have talked share the conviction, that the scale of research in the electric power field is too small and that the allocation of research effort is too haphazard. The electric power industry is too great and important, and its potentials are far too vast, for its research strength to depend on the initiative and the particular interests of individual electric utility executives who are harried with operating responsibilities or on the 'fallout' from research programs directed at altogether different objectives."

The date was June 4, 1963—2 years before the Northeast blackout, 10 years before the Arab oil embargo, and 14 years before the winter of 1977. The speaker was Joseph C. Swidler, chairman of the Federal Power Commission at that time. What he was proposing to his audience of Edison Electric Institute members, who were meeting in Denver that summer day, was an unprecedented idea for the electric utility industry. That idea was to result in the formation of the Electric Power Research Institute 10 years later.

"The nation's number one industry can afford a research program scaled to its needs and opportunities. It cannot afford the risk of lost opportunities and delayed progress that is inherent in the present lack of system or direction in research. I have no prescription for curing the research problems of the industry, but I should like to propose a small step that could lead to some improvement."

After acknowledging the organizational difficulties that beset an industry composed of four separate institutional groups and some 3500 separate entities, Swidler's so-called small step was to help organize a committee to consider establishing a permanent industrywide research organization. It was this committee —whose members represented the various sectors of the industry, the manufacturers, and the research community— that laid the plans for the creation of the Electric Research Council and issued a task force report in 1971 calling for the establishment of a "full-time organization charged with the development of

"The real purpose of the Advisory Council is to provide EPRI with some windows on the world that it could not have without going outside the Institute."

research plans and the vigorous implementation of programs."

Eighteen months later, in January 1973, EPRI was formed.

The man who first voiced the need for an organization like EPRI back in Denver in 1963, Joseph Swidler, has remained a firm supporter of the Institute.

"In some ways, EPRI has exceeded the hopes that I had first envisioned—the breadth of EPRI's work, the organization of its staff, and the integration EPRI has developed with the federal establishment and private industry is well beyond what I had anticipated," Swidler said during a recent interview in his Washington, D.C., office, where he has resumed the practice of law as a partner in the firm of Leva, Hawes, Symington, Martin & Oppenheimer.

Swidler admits he is surprised at how fast EPRI has grown and says this growth can be traced to the enormous increase and emphasis on energy research that has taken place in the last decade. "There was just no time for EPRI to dwell on its growing pains like other new organizations," he states.

Speaking at the annual convention of the Edison Electric Institute in San Diego in June 1972, six months before EPRI was to begin functioning as a research institute, Swidler commented that the "great potential advantage of the industry approach is the opportunity for close integration of R&D and the practical operation of the nation's power systems —with the industry's managers contributing a flow of problems and research suggestions and the research and development arm responding with research concepts and developmental hardware and receiving a feedback of operating results."

What Swidler meant by the "industry approach" refers to an amendment then being considered in Congress that would have created a federal power research and development board. Such an agency would have placed a tax on all energy generated throughout the country to fund a government-organized research program. Swidler, along with other electric utility leaders, felt that it would be better for the industry to finance and manage its own comprehensive research program. (The widespread acceptance of EPRI by both government and industry resulted in the recent withdrawal of that amendment.)

"I do think it would be helpful if EPRI did some research in its own laboratories so that it could function on the basis of some in-house experience."

A man very much respected by legislators and business leaders alike, Swidler said that when EPRI first began he imagined it would develop some in-house research capability. He says he feels the same about this today as he felt back in 1972 when he stated at the EEI convention that the electric power industry needed to declare its independence in research work "by taking responsibility for carrying out a part of its research program with its own people, in its own laboratories and test facilities.

"This would not mean disturbing contract research that is showing adequate results. Certainly it does not mean breaking up effective research teams presently at work for manufacturers, universities, and private research institutions. On the contrary, when their projects and methods conform to the industry program, existing research teams should receive strong support."

He said at that time that "this means avoiding total dependence on outside groups, with the inherent limitations of direction and control, the awkwardness of arrangements for providing necessary facilities and installations, and the possibility of conflicts. It means carrying on the work directly when the pace of progress by contract is too slow, when the goals cannot be adequately identified in a contract, when greater flexibility is needed, or when the required facilities are too expensive to be entrusted to a contractor."

He says that what he had envisioned for EPRI was something on the order of AT&T's Bell Labs.

"I didn't think of the Bell Labs as the perfect model, except that it demonstrated a possibility for an in-house industry research capability. I don't mean that EPRI should ever confine itself to in-house research, but I do think it would be helpful if EPRI did some research in its

own laboratories so that it could function on the basis of some in-house experience. And I still think that day will come," he states.

Swidler believes that technological improvement in the power industry has become more than an industry objective. "In view of the impact of power generation on the environment, and the greater fears for the future, it has become a national goal of high priority to find technical solutions that will permit a reconciliation between expansion of power supply and environmental protection on terms that do not jeopardize the safety of our citizens or of future generations," remarks Swidler.

Specifically, the former chairman of the Federal Power Commission refers to the control of air pollution, the dissipation or use of waste heat without damage to marine life, and protection against radiological hazards. In addition, he cites a number of energy goals he hopes the U.S. can achieve, such as using fully our nation's abundant coal supplies in place of oil, improving the economy and reliability of generating sources, increasing the efficiency in producing and using energy, and improving transmission technology to lessen the drain on land and scenic resources without escalating transmission costs to prohibitive levels.

These types of concerns are presently being addressed through the EPRI Advisory Council committee Swidler serves on—the Committee on Power Sources and Uses. This committee is one of four in the Advisory Council; the other three are involved with questions on environment and ecology, national issues affecting EPRI, and communications.

"The Advisory Council and the EPRI Board are still attempting to define an appropriate relationship between the Council on the one hand, and the Board and the EPRI staff on the other. And I can't say that the process is nearing completion, although I think the establishment of the four committees was a step in that direction," says Swidler.

Speaking in his characteristically thoughtful manner, Swidler states that the recent move on the part of the Advisory Council to set up a plan by which there could be regular interaction with the EPRI Board is another desirable step. "In the past, the Advisory Council has pretty well been limited to advising the staff. I think this is not a totally satisfactory arrangement, and it is now in the process of being changed. The Council continues to feel its way toward establishing the most productive kind of relationship possible with the EPRI Board and staff."

"The breadth of EPRI's work, the organization of its staff, and the integration EPRI has developed with the federal establishment and private industry is well beyond what I had anticipated."

Swidler hopes that all the Council committees will be able to provide some policy contributions. He emphasizes, however, that the Council is well aware of its advisory role and seeks no other.

"The real purpose of the Council," he says, "is to provide EPRI with some windows on the world that it could not have without going outside the Institute." The former chairman of the New York State Public Service Commission feels that an important feature of the Council is that it provides a method by which the utility regulatory community can keep in touch with the work under way at EPRI.

"When EPRI was established, and the founders were attempting to define the proper relationship between EPRI and the regulatory community, the organizing group, of which I was a member, realized that EPRI could not get going without the approval of the regulators." Swidler says that the "regulators took the position that they did not want to be part of EPRI management because in certain instances this could impede their freedom to voice objections or criticisms. They did request, however, that an advisory council be created and that seven places be reserved on that council for representatives of the National Association of Regulatory Utility Commissioners."

Swidler's extensive background in public service and in industry has provided him with a sharp insight into EPRI's relationship with federal agencies, as well as with the regulatory community. In a recent report drafted by the Advisory

Council Committee on Power Sources and Uses, it was suggested that a necessary function of EPRI may be to act as a catalyst in reminding key energy agencies and the public when government programs are lacking.

In speaking of ERDA's relationship with EPRI, Swidler explains that because ERDA must adapt its procedures so that its expenditures are authorized by Congress, the priorities given to develop different energy technologies are not always those the top management at ERDA would like to see.

"A possible way to remedy this situation, at least in some instances, is for EPRI, acting of course within its stated guidelines, to exert influence in the direction of a less-politicized system of determining research priorities and in favor of a system that reduces the paperwork and expedites the allocation of research funds. You sometimes hear it said that on a contributory plan, where the industry puts up part of the money and the government the balance, it is hardly worthwhile going to ERDA because of the additional expense and delays incurred," says Swidler.

He admits this is not an ideal situation, but understands that it is a difficult one for ERDA to rectify. He believes that EPRI can be of "invaluable help in that sort of climate."

At the same time, Swidler feels that EPRI could also serve as a catalyst in working with the government on demonstration projects—projects that frequently cost hundreds of millions of dollars.

"Up to now, Congress has shown an unwillingness to provide most of the funds and to take most of the risks in demonstrating new energy technologies," he remarks, noting that because of the huge scale of investment involved, EPRI cannot afford to be the prime sponsor for large-scale demonstrations.

"Instead, EPRI could act as a catalyst to bring the project together," says Swidler. He suggests that EPRI could help determine which demonstrations are desirable, on what scale, and then work with the appropriate federal agencies to initiate the demonstration program. This type of action, he feels, could shorten the project's time frame, especially in those phases of the demonstration where the costs are fairly low and where EPRI's ability to handle the paperwork could result in the demonstration getting started faster than if federal funds were required at every stage.

Swidler has long understood that there are many areas in which research breakthroughs, although not of "cosmic importance," could, nevertheless, offer tremendous economy incentives. He says that in the nation's largest single industry, "The leverage is so great that any technological breakthrough may save more than the whole cost of the industry's share of the EPRI program over many years.

"For example, boiler tube leaks account for a substantial proportion of units out of service for repairs. A leak may shut down a plant representing a quarter-billion-dollar investment, entail significant repair costs, and force the use of far more expensive supply sources. If the industry, through EPRI's efforts, is able to improve pipe metallurgy and welding so that unscheduled outages caused by such leaks are reduced by half, the savings would represent hundreds of millions of dollars a year."

Before the introduction of EPRI, Swidler had voiced his concern over not only the lack of industry emphasis on R&D, but also the effect it had on making the industry less attractive to some of the nation's young technical people. Some years ago he said, "One of the greatest hidden costs of the industry's approach to R&D is that it deflects the best technical talent to other industries."

But with EPRI and the recent importance attached to electric energy research, he now believes there are many more opportunities for young people in the utility industry.

Swidler asserts that the utility industry is beginning to overcome its image of being nonaggressive technologically. He believes this image could be overcome even faster if EPRI assumed a direct research role rather than relying exclusively on contractors.

"The greatest change will come about as the industry takes advantage of new technology," he says. "For example, some of the equipment for desulfurization will require chemical engineering training and other technologies will demand a variety of disciplines. I think the future opportunities within the electric utility industry will not be limited to electrical and civil engineers. This will tend to give the industry a broader perspective, as well as a more attractive image to bright technical people coming out of the universities."

What does the veteran public official and regulator feel is the main contribution EPRI can make to the industry? "What the industry has always needed," he asserts, "was a research commitment, a continuous search for the most productive approaches, a total immersion in the world of science and research under the best available scientific leadership. I believe EPRI has brought that needed order to electric power research planning, and I'm gratified I was able to help."

Joseph C. Swidler has held a number of public positions throughout his career: director of the Institute for Public Policy Alternatives in the State University of New York, 1974–1975; chairman of the New York State Public Service Commission, 1970–1974; and chairman of the Federal Power Commission, 1961–1966, by appointment of President John F. Kennedy.

Swidler began his public career in May 1933, when he became assistant solicitor of the Department of the Interior. Later that year, he became power attorney for the then recently created Tennessee Valley Authority and served with TVA until 1957. From 1945 until 1957, Swidler was TVA's general counsel and secretary, also serving as chairman of the Board of the TVA Retirement System.

The man whom some call the founder of EPRI remains active in the affairs of EPRI through his membership on the EPRI Advisory Council and his longtime relationships with EPRI management. He also serves as a member of the Commission on Critical Choices for Americans and on the National Academy of Public Administration.

At the Institute

Energy Film Available

"Energy Realities" is a new 16-mm color-sound motion picture designed to let the public know the facts behind the energy choices facing the nation. Produced by EPRI, the film takes a hard look at present and future energy conversion technologies and is now available for purchase.

The film has an interesting and entertaining approach to the energy picture. The on-camera host is an EPRI engineer who guides the audience through an overview of all the popular energy options. Laboratories and field facilities throughout the world are visited, and the research scientists themselves explain why some of the advanced energy sources will not be available until the next century.

The film provides a positive but realistic look at solar and other energy options. It urges conservation and concludes that because of continuing growth and the unavailability of other proven sources, coal and uranium will have to assume much of our energy burden over the next 20 or more years.

Ideal for civic groups, school audiences, and public service television, the 22-minute presentation helps to dispel some of the public myths on the energy situation. For example, the film points out that solar power and other new energy sources are not immediate solutions to the energy problem; rather, solar and other developing energy technologies, such as geothermal and fusion, will still provide only a small share of our energy needs by the year 2000.

The EPRI film was made in cooperation with the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association.

The print cost is being kept as low as possible to encourage EPRI members to distribute prints widely. The price is $135.00 each; bulk prices available on request. Preview print requests and purchase orders should be sent to Film Counselors, Inc., 500 Fifth Avenue, New York, NY 10036.

Exchange of Nuclear Power Research Information

Eight European electric utilities in seven countries have agreed with EPRI to exchange information on nuclear fuel and reactor core performance for a year.

EPRI's policy is to place in the public domain the information it develops in the course of its research. Therefore, the parties agreed that they will exchange general information about their current fuel performance projects and future plans, so that they may better administer their own research programs.

EPRI and the European utilities will routinely exchange detailed data and information on specific projects through written and oral reports. The agreement calls for such information to be kept in confidence for five years to avoid disclosure that might compromise possible patent interests.

The scope of information covered by the agreement includes data on nuclear fuel, cladding properties and behavior, fuel rod tests in test reactors or power reactors, fuel bundle performance evaluations in power reactors, results of fuel rod modeling codes and analyses, and core performance analyses.

The European parties to the agreement are major or national utilities in West Germany, Switzerland, the Netherlands, Denmark, Norway, Sweden, and Finland. The association (dubbed TUG for The Utility Group) includes Germany's largest privately owned utility, Rheinisch-Westfälisches Elektrizitätswerk; Bernische Kraftwerke AG of Bern, Switzerland; N. V. Gemeenschappelijke Kernenergiecentrale of Arnheim, Netherlands; ELSAM Kraftvaerksgruppen of Fredericia, Denmark; the State Power System of Norway; the State Power Board and the South Sweden Power Company, Sweden; and Teollisuuden Voima OY, Finland.

Final Plans Reviewed for BEST Facility

As a result of information presented at a February workshop in New Orleans, the Battery Energy Storage Test (BEST) Facility is continuing on its present schedule, which calls for completion in late 1979.

The BEST Facility is being built at a Public Service Electric and Gas. Co. (PSE&G) substation in Hillsborough Township, New Jersey, so that after extensive component testing by the developer, battery system performance can be tested and characterized on an actual utility system.

PSE&G presented the workshop with the final design. The facility will include three test bays, electrical interface equipment space, data analysis rooms, a shop area, an automated control room, facility services, and office space. The facility is jointly funded by EPRI, ERDA, and PSE&G.

The EPRI–ERDA battery development contractors include Argonne National Laboratory, Atomics International, Dow Chemical Co., Energy Development Associates (EDA), ESB, Inc., Ford Motor Co., and General Electric Co. The developers endorsed the concept of the facility and its design and presented updated information on their battery design and development schedules to the 50 participants attending the workshop. A zinc-chlorine battery developed by EDA is likely to be the first advanced energy storage battery tested at the facility.

In addition to the battery developers, the workshop group included battery manufacturers, power converter and electrical equipment suppliers, utilities, EPRI Ad Hoc committees, and representatives from EPRI and ERDA. A number of key recommendations were discussed, including criteria for selecting batteries for facility testing and methods for analyzing test data.

Other topics included electrical interface equipment for the facility and for commercial applications, lead-acid batteries for the facility, lead-acid battery application economics, and battery cost-estimating methods.

An artist's rendering of the Battery Energy Storage Test (BEST) Facility presented at a recent workshop. The drawing of the $8 million facility shows (left) the three electric power converters and one of the bays where the tests will take place. On the right is the automated control room and the low-rise section containing offices and conference rooms.

Key members of the BEST Program Management Team review results of the three-day workshop in New Orleans: (seated, from left) Tom Schneider, program manager, EPRI Energy Storage Program; Charlie Smith, ERDA program manager for BEST; and Jim Beck, EPRI program manager for BEST; (standing, from left) ERDA's Howard Feibus and Kurt Klunder of the BEST Facility Program Planning Group.

Starr Talks on Solar Power

The use of sunlight to generate electricity may become "commercially attractive" to electric utilities by the end of the century.

This development, according to EPRI President Chauncey Starr, will take place only if "all goes well" in the solar-thermal electric research and development program now in its initial phases. Dr. Starr addressed the annual meeting of the American Association for the Advancement of Science on February 22 in Denver.

If solar energy is to be an important power producer by the end of the century, all the commercial plants will have to be constructed in the last decade of the century, Dr. Starr pointed out, adding that a demonstration plant of moderate size will not be operational before 1990.

"We have projected that solar electric systems might be able to contribute about 1% to the total electricity usage at the end of the century," he noted. This would require the construction of 250 solar generating units, 100-MW capacity each, in a period of 10 years. According to Dr. Starr this is "an aggressive and perhaps optimistic goal."

The integration of a new technology, such as solar-thermal electricity generation, into an electric utility system requires that it be economically competitive with other power systems, he stressed. Dr. Starr said that any new generating system must meet reliability and maintenance tests, have resource availability (sunlight, in this case), and have the necessary system capability and flexibility to capture a substantial share of the power generation market.

"The most crucial step today in solar-thermal electric research and development is the engineering demonstration of units having a capacity of approximately 10 MWe each," Dr. Starr stated. Such demonstrations would allow a thorough evaluation of engineering features and utility system compatibility.

Superconducting Generator Prototype

Two competitive designs for a 300-MW ac superconducting generator are nearing completion by Westinghouse Electric Corp. and General Electric Co., working under separate EPRI contracts. The possibility of building a prototype based on these designs was the purpose of two recent meetings between EPRI officials and representatives of the contractors.

To date, the largest prototype of a superconducting generator is a 5-MW machine built at Westinghouse; the machine discussed at the EPRI meetings would be between 100 MW and 300 MW, making it the largest in the world.

According to industry and EPRI researchers familiar with the technology, the consequences of commercializing superconducting generators would be significant to the power industry. For example, the two design studies indicate that superconducting generators would have half the generating losses of conventional generators. Other advantages of the superconducting generators, according to Mario Rabinowitz, a senior scientist of the Electrical Systems Division, are their reduced size and weight, lower capital cost, and greater stability.

Ray Towne (standing) of Westinghouse Electric Corp. presents the preliminary superconducting generator design his company is working on under a contract with EPRI. Listening to the presentation at a recent meeting are (counterclockwise) Mario Rabinowitz, EPRI; Joe Jackson, EPRI; Captain Hugh Southall, U.S. Air Force; Hampton Barnett, TVA; and Dr. Gerry Wilson of MIT.

Says Rabinowitz, "The superconducting generator represents the first major technology change in the generator field. But all the advantages of the superconducting generators could be outweighed by one factor—reliability. During the prototype testing phase, however, the reliability of the superconducting generator may very well be demonstrated to be equal to that of conventional machines."

Canadian Visitors

EPRI's study of the biological effects of electric fields from high-voltage transmission lines was the topic of a recent visit from a team of Canadian officials planning future research in this area. The visit initiated information exchange between EPRI and the Institut de Recherche de l'Hydro-Quebec (IREQ), the principal laboratory for electric research in Canada. Representing EPRI in the picture on the left are (l to r) John Dougherty, director of the Electrical Systems Division; Harry Kornberg, program manager in the Energy Analysis and Environment Division; Karen Ray Brower, member of the Research Staff in that division; and Ric Rudman, director of the Planning Staff. The Canadian team pictured on the right are (l to r) P. S. Maruvada, IREQ; Dr. Lionel Boulet, IREQ; Dr. Jacques Billette, Institut de Cardiologie de Montreal; and Dr. A. Arsenault, Health Directorate Hydro-Quebec.

New Nuclear Project Group Established

The Nuclear Power Division formed a new project group in February. The director of the division, Milt Levenson, explained that the steam generator project will address problems arising from the operation and maintenance of large-scale steam generators used by PWRs. The new project group will report directly to the division office and is being staffed by Bill Layman, project director, and Lou Martel, technical director.

Unlike most programs and projects at EPRI, the steam generator project will not receive its financial support from Institute funds. Although the project will be managed and staffed by EPRI personnel, the funding will come directly from a group of utilities who own PWRs and have experienced specific research needs related to the technology.

According to Levenson, a number of these utilities (known as the PWR Owners Group) approached EPRI last fall with a request for the Institute's services in managing a research project related to their specific needs. Because the research needs did not pertain to the utility industry as a whole, and because the project would be costly (estimates are in the multimillion-dollar range), the PWR Owners Group specified that the funding would come from direct contributions from participating utilities. EPRI's Board of Directors approved the financial arrangement at their November meeting.

There are 26 utilities in the U.S. that either own PWRs or have them on order, according to Levenson. Of these 26 utilities, 12 have indicated as of March 1 that they will be participants in the research project. Coordinating the participants is an interim executive committee chaired by Bill Caldwell of Consolidated Edison Co. of New York, with Al Schmidt of Florida Power & Light Co. as vice chairman. Other members include Walter Fee, Northeast Utilities Service Corp.; Ruble A. Thomas, Southern Company Services, Inc.; R. L. Haueter, Consumers Power Co.; A. W. Wofford, Long Island Lighting Co.; and W. L. Riedel, Baltimore Gas and Electric Co.

The steam generator project is presently staffed only by Layman and Martel. Layman was formerly a program manager in the Nuclear Engineering and Operations Department; Martel was program manager in the Nuclear Systems and Materials Department. Levenson noted that one or two people may be transferred to the new project group from other Nuclear Power Division offices to augment the staff and that new hires are planned.

EPRI Administration Division Director David Saxe noted that approval was given at the February EPRI Board of Directors meeting for a similar financial arrangement for three research projects requested by a group of Kansas utilities. The projects will be managed by EPRI but funded by the Kansas utilities. In terms of funding, they are smaller than the steam generator project.

Nuclear Power Study Group

The semiannual meeting of the Nuclear Reactor Pressure Vessel Study Group was held recently at EPRI with about 40 people in attendance. The study group includes experts in the field of nuclear reactor pressure vessel design, fabrication, and analysis. At the meeting, there were representatives from the United Kingdom Atomic Energy Authority; the publicly owned French electric utility, Electricité de France; IHI, a Japanese pressure vessel manufacturer; four major U.S. reactor vendors; the Nuclear Regulatory Commission (NRC); and various universities and consulting firms. Results of the meeting will be used by EPRI to help plan its program in pressure vessel integrity. Shown here at the meeting are (from left) Dr. Spencer Bush, a senior staff consultant at Battelle, Pacific Northwest Laboratory and a member of the Advisory Committee on Reactor Safety, NRC; Dr. Roy Nichols, deputy director of the Risley Research Laboratories, United Kingdom Atomic Energy Authority; and Dr. Karl Stahlkopf, EPRI program manager for the Nuclear Pressure Boundary Program.

Rotating Electrical Machinery Program Manager Named

Joe Jackson, formerly manager of the generator engineering section in General Electric Co.'s Medium Steam Turbine-Generators Department, was recently named EPRI manager of the Rotating Electrical Machinery (REM) Program.

The REM Program is geared to improving the reliability of conventional generators by such projects as the development of improved nonmagnetic retaining rings; control of subsynchronous resonance; and the development of an analytic model to better define synchronous machine characteristics.

A major effort of the program will be directed to the design and construction of a prototype superconducting generator that promises higher efficiencies and lower weight and costs.

The Electrical Systems Division staff in EPRI's Washington, D.C., office has also recently added two members: Joe Piscioneri, formerly of Northeast Utilities, and Bruce Bernstein, formerly of Sun Chemical Corp. A third person, who will serve as regional manager for the Electrical Systems Division, will be added in the near future. All three will be project managers for research that is under way in the East, as well as help provide closer liaison with ERDA and other government agencies.

Strange Joins EPRI Washington Office

Robert L. Loftness, director of EPRI's Washington, D.C., office, reports that Ben W. Strange, a veteran utility communications manager, has joined the EPRI staff.

Strange came to Washington in 1973 to head up Potomac Electric Power Co.'s nuclear information department. Shortly after Pepco deferred its first nuclear plant program, Strange went to the FEA to manage the new Utilities Conservation Action Now (UCAN) program and later became a project officer for the agency, pursuing innovative data-gathering hardware for the electric rate demonstration program and overseeing an electronic igniter experiment with Brooklyn Union Gas Co.

Having both electric and gas utility experience, Strange joined Consumers Power Co. in Jackson, Michigan, in the mid-1960s in employee communications and financial communications. He was later assigned numerous community relations and general public relations duties.

Strange has also owned and operated weekly newspapers in northwestern Ohio.

He will serve EPRI as assistant to the director of the Washington office, and his duties will include press relations in the Washington, D.C., area.

Project Highlights

Desalting Technique Conserves Fresh Water

Tests now under way at a site near Firebaugh, California, could help conserve the state's freshwater supplies by developing a process for treating agricultural waste water so it can be used in power plant cooling systems. The waste water is brackish agricultural drain water that is too salty to be reused for irrigation.

The tests mark the second half of a three-year research project jointly funded by EPRI, Pacific Gas and Electric Co., Southern California Edison Co., the Los Angeles Department of Water and Power, and the California Department of Water Resources (DWR), which will continue to be responsible for the overall management of the project.

The first 18 months of the project, performed under a DWR contract, were geared to laboratory experiments and the design, assembly, and testing of the Firebaugh pilot plant. Hugo Sephton and Gerhard Klein of the University of California, Berkeley, proposed the process and conducted the tests at the University of California's Sea Water Conversion Laboratory.

The pilot plant at Firebaugh, California, where researchers are studying a method of treating agricultural waste water so that it can be used for power plant cooling. At the base of the cooling tower is the concrete recirculating water basin. The black plastic-covered basin shelters about 5000 gallons of softened agricultural waste water that is being stored for further testing.

According to John Maulbetsch, manager of the EPRI Water Quality Control and Heat Rejection Program, the process has already been proven in the laboratory, but whether it is economically feasible will not be known until the pilot tests under field conditions at Firebaugh are completed.

If proven reliable and economical, the process would also help solve the problem of agricultural waste water disposal in California, as well as in other states.

The process involves several steps. Brackish irrigation drain water is pretreated by passing it through a resin bed to reduce the calcium content and scale-forming tendencies before its use in power plant heat exchangers. Next, the treated water is reused several times for power plant cooling, until the salt concentration becomes so high that some water must be replaced with less salty water. In the third step, the salty cooling water is removed from the cooling system and concentrated further in an advanced technology vertical tube evaporator. The concentrated fluid is then used to regenerate the resin beds used in the first step, which otherwise would have to be treated with new chemicals at significant cost.

Ecological Effects of Rights-of-Way

What are some of the ecological effects that can occur when utility companies construct power transmission lines? What are the possible effects on vegetation and wildlife from clearing and maintaining power line rights-of-way through forests, grasslands, and agricultural lands?

A new study has been initiated by EPRI to answer these types of questions and to determine the data available in this area.

Asplundh Environmental Services of Willow Grove, Pennsylvania, has been selected as the contractor and will review the current literature and research on the subject. Researchers at Asplundh will also be interviewing utility representatives who have been involved in right-of-way clearing and in power line construction and maintenance.

"Many utility employees and environmental groups are familiar with right-of-way effects for their own systems, but this will be the first major attempt to compile national information on this subject," says Karen Ray Brower of the EPRI Environmental Assessment Department.

As part of the study, different regions of the country will be surveyed to determine how rights-of-way impact various ecosystems. Erosion resulting from clearing and the use of heavy construction equipment, for example, may be a problem in areas with certain types of soil, climate, and vegetation, but of little concern in other areas with different conditions. After evaluating the information, Asplundh will identify those major ecological questions that remain unanswered and will recommend appropriate research.

"Essentially, the project will enable utilities to document potential ecological effects based on research results that were previously inaccessible," says Brower, and adds that this will reduce research duplication, help pinpoint areas requiring additional research, and allow utility decision makers to identify the most ecologically sound approach to right-of-way management.

EPRI Negotiates 29 Contracts

Number	Title	Duration	Funding ($000)	Contractor / EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP226-3	Development of the Zinc-Chlorine Battery for Utility Applications	27 months	3800.0	Energy Development Associates *J. Birk*
RP323-2	Fusion Experimental Power Reactor (EPR) Design Tasks	19 months	1200.0	General Atomic Co. *F. Scott*
RP645-4	A Preliminary Proposal to Study High Thermal Efficiency, Radiation-based Advanced Fusion Reactors	4 months	24.6	Mathematical Sciences Northwest, Inc *N. Amherd*
RP789-1	Improved Heat Pump Performance and Reliability in Northern Climates	15 months	100.0	Niagara Mohawk Power Corp. *J. Pepper*
RP898-1	Additional Boiler Corrosion Study Firing Coal-Refuse Mixture at Wisconsin Electric Oak Creek Unit No. 7	18 months	74.8	Combustion Engineering, Inc. *C. McGowin*
RP916-1	Clean Distillate Fuels Process Development Pilot Plant Conceptual Study	5 months	63.0	Foster Wheeler Energy Corp *H. Lebowitz*
RP923-1	Comparison of Solar Absorption and Vapor Compression Residential Cooling Systems	24 months	56.0	Texas Electric Service Co *J. Cummings*
RP982-2	Feasibility Study of Dry Sorbent SO_2 Removal	3 months	32.5	Acurex Aerotherm *D. Teixeira*
RP982-3	Evaluation of Performance Data for Fabric Filters	12 months	49.7	Illinois Institute of Technology *R. Carr*
Nuclear Power Division				
RP613-3	Benchmark Analysis for Transuranics at 10nCi/g Level	2 months	8.9	General Electric Co. *M. Lapides*
RP771-2	Analysis of Reliability / Availability Data Systems	6 months	24.7	NUS Corp. *R. Long*
RP813-1	Parametric Study of Critical Heat Flux Data	29 months	219.9	Columbia University *K. Nilsson*
RP816-1	Assessment of 1E Equipment Aging and Qualifications Technology	17 months	100.00	Gulf States Utilities Co. *D. Cain*
RP886-2	Evaluation and Prediction of Neutron Embrittlement in Reactor Pressure Vessel Materials	36 months	1100.0	Naval Research Laboratory, Washington, D.C. *T. Marston*
RP887-1	Operational Transients Controlling Parameters Study	4 months	49.8	Energy Inc. *L. Agee*

FBC Boiler Study Concluded

Information to successfully design a commercial fluidized-bed boiler is inadequate at this time, although sufficient information may be available to demonstrate this new type of boiler by the early 1980s.

This was one of the key conclusions of an EPRI report on a study performed by Babcock & Wilcox Co., Alliance, Ohio. The study assessed the current status of fluidized-bed combustion boilers and identified the additional research needed so that the boilers can be used commercially by the electric utility industry.

Coal makes up about 90% of the nation's estimated recoverable fossil fuel reserves, but much of this coal is difficult to burn without violating clean air standards. Although fluidized-bed boilers burn coal to produce electricity, the process is unusual in that it may control sulfur dioxide and oxides of nitrogen and eliminate the need for additional pollution control systems.

The fluidized-bed process mixes crushed coal and limestone or dolomite and fluidizes the mixture by blowing hot combustion air through it. When the mixture burns, much of the coal's sulfur reacts with the calcium in the limestone or dolomite to form a solid sulfate product that can be removed along with the ash. At the same time, the preferred combustion temperature is low enough so that nitric oxide pollution is reduced. (Nitric oxide formation is favored by a high combustion temperature).

Researchers working on the EPRI study found that to remove sulfur, fluidized-bed boilers currently need three times the limestone that theoretically would be indicated. Using this much limestone could be impractical and expensive, and the report recommends studies on identifying ways to reduce its consumption.

The report also recommends studies to evaluate the potential costs of fluidized-bed boilers so that electric utilities can compare these costs with conventional coal boilers as soon as possible.

The report also notes the need to develop handling techniques for the boiler's solid waste. This would probably entail either regenerating the waste or disposing of it in landfills.

Number	*Title*	*Duration*	*Funding ($000)*	*Contractor / EPRI Project Manager*
RP889-2	Development of a Systems Transients Simulator	4 months	50.0	Energy Inc. *L. Agee*
RP957-1	Measurements of Fission Product Beta and Gamma Spectra for Correlating Decay Heat Data	13 months	94.9	IRT Corp. *F. Rahn*
RP963-1	Multidimensional Two-Phase Flow Simulation for Steam Generator Modeling	24 months	250.0	University of Pittsburgh *L. Agee*
RP969-1	Solubility of Corrosive Salts in Dry Steam	36 months	164.1	University of Georgia *T. Passell*
Electrical Systems Division				
RP849-2	Determining Load Characteristics for Transient Performance	17 months	231.8	Institut de Recherche de l'Hydro-Quebec *T. Yau*
RP849-4	Determining Load Characteristics for Transient Performance	44 months	25.0	Michigan State University *T. Yau*
RP933-1	Research to Determine the Acceptable Emergency Operating Temperatures for Extruded Dielectric Cables—Phase I	12 months	150.8	Institut de Recherche de l'Hydro-Quebec *W. Shula*
RP7856-1	Underground Obstacle Detector	25 months	167.7	Ohio State University Research Foundation *T. Rodenbaugh*
Energy Analysis and Environment Division				
RP934-1	Field Evaluation of Possible Effects of HV Lines on the Honeybee	27 months	88.7	Bioconcern *H. Kornberg*
RP937-1	In Vitro Toxicity Studies on Fossil Fuel Combustion Particulates	12 months	267.3	Battelle, Columbus Laboratories *J. McCarroll*
RP949-1	Primary Energy Resources and Reserves Estimation	13 months	150.0	Massachusetts Institute of Technology *J. Platt*
RP1010-1	Extensions of Water Supply Data Base for Evaluation of R&D Programs	15 months	159.3	University of Arizona *R. Riley*
RP1012-1	Incorporating Uncertainty in Energy Supply Models	8 months	43.5	The Futures Group *M. Searl*
RP1014-1	Revision and Extension of the Energy Technology Assessment Model (ETA)	12 months	100.0	Stanford University *S. Peck*

Improved Vacuum Circuit Interrupters

Vacuum circuit interrupters that can handle nearly twice the voltage and 50% more current than units in commercial service are being developed at the General Electric Research and Development Center under a recently awarded three-year, $1.65 million contract from EPRI.

General Electric researchers expect to build and test four different vacuum interrupters. The best features of each would then be incorporated into a final prototype with a targeted interruption capability of 63,000–80,000 A at 72,000–80,000 V.

For about 15 years vacuum circuit breakers have been operating commercially in the 15,000–38,000 V range with an interruption capability up to 31,000 A. Now they are being considered for high-voltage lines, where present-day circuit breakers employ oil, air, or special gases to control and extinguish the arcs.

The new EPRI–General Electric high-power vacuum interrupters will be based on a unique structure developed at the General Electric Research and Development Center by physicist Joseph A. Rich. In laboratory tests, the novel structure has successfully carried peak currents up to 240,000 A without damage.

"Although the vacuum interrupter appears to be a relatively simple device, its operation is a highly complex mixture of plasma physics, high-field physics, metallurgy, and chemistry," says Narain Hingorani, EPRI program manager for substations.

Hingorani points out that the development of higher power vacuum interrupters depends on new understanding of electron emission in high electric fields, the physics of vacuum arcs, dielectric breakdown, metallurgy of contact materials, and insulation behavior.

Among the advantages of vacuum breakers over conventional oil and gas-blast equipment listed by Hingorani are minimal maintenance, compactness, quiet operation, rapid voltage recovery, and environmental compatibility.

A new high-power vacuum circuit interrupter that can handle nearly twice the voltage and 50% more current than units in commercial service is being developed at the General Electric Research and Development Center under an EPRI contract. A. Harry Sharbaugh (right), manager of the center's plasma physics branch, and physicist George A. Farrall check the new device prior to tests. It is based on a unique structure developed by Joseph A. Rich of General Electric and is being designed to protect future high-voltage transmission lines and stations from damage from high fault currents due to lightning or other causes.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

Results of many recently completed research projects reported this month are applicable to several programs within the division. For example, high-strength porcelain developed in the Overhead Line Program will be equally useful in substations and distribution systems. The same is true of a new zinc oxide lightning arrester. The light-fired thyristors developed in the dc converter station subprogram will find applications in ac transmission as a volt-ampere-reactive control device and in distribution systems with battery or fuel cell energy storage device controls. Projects such as the control of tree growth, which is being developed under the Distribution Program, will be vitally important to compact transmission line design.

We are fully aware of what the majority of the industry expects of our research program. As we move into the fourth full year of directed research, we have been encouraged by many to concentrate most of our efforts on technologies that promise near-term results. Others would prefer that a proper balance be maintained between near-, mid-, and long-term research. With the combined wisdom of task force inputs and our own assessment of viable technical alternatives, we are confident of mounting a refined and redirected research effort that will be of maximum benefit to the industry.

One area that has recently received renewed effort and a clearer definition of objectives is the Rotating Electrical Machinery (REM) Program. This is evidenced by the Division Committee's endorsement of a substantial five-year budget for REM ($19.1 million, or 11% of the division's 1978–1982 budget). The major emphasis in the REM Program will be on the critical problems involved in improving the reliability of conventional generators. Typical problems to be addressed are:

- Development of a better nonmagnetic retaining ring
- Control of subsynchronous resonance
- Development of an analytic model to better define the characteristics of synchronous machines

A substantial effort will be directed to the design and construction of a prototype superconducting generator of higher efficiency, less weight, and lower cost.

DISTRIBUTION

Underground distribution

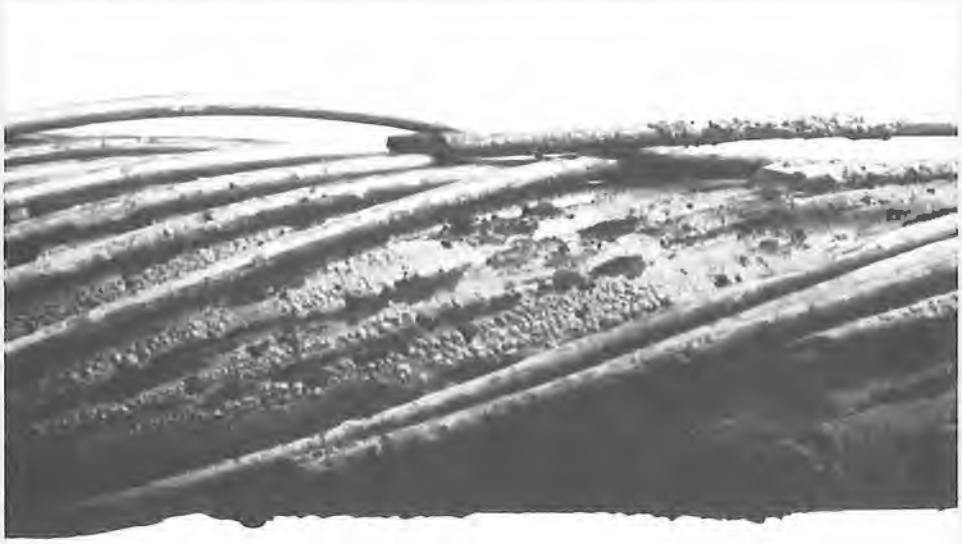
How to avoid or to minimize contaminants is a major quality control problem in the manufacture of high-molecular-weight polyethylene (HMWPE) and cross-linked polyethylene (XLPE) insulated distribution cable. Voids or inclusions lower the corona discharge voltage and dielectric strength of the insulation. They can also serve as sites from which electrochemical trees can develop in wet environments.

A project with United Technologies Corp. is concerned with the use of laser scattering patterns to detect voids and contaminants during the manufacturing process (RP794). Both HMWPE and XLPE are transparent to far-infrared (FIR) laser beams. Hence, inclusions show up prominently.

With only 9 months of this 20-month project completed, the contractor reports the ability to detect contaminants or voids as small as 20–50 micrometers (1–2 mils). The end product, of course, is development of a detection system that would be rugged, economical, and easily operated by cable manufacturers. But this contract is limited

Figure 1 Laser beam detectors in the far-infrared spectrum are under development to reveal voids and contaminants in solid dielectric insulation.

Figure 2 Typical corrosion of concentric neutrals surrounding buried cables.



to a feasibility study to prove the concepts. If successful, a follow-on project could lead to specification and development of a prototype FIR detector suitable for factory or diagnostic use. *Project Manager: Robert Tackaberry*

Corrosion of concentric neutrals surrounding buried cable continues to rate as a problem of high priority among utilities. The Distribution Task Force and the EPRI staff have organized a research subprogram in an attempt to solve the problem. A number of projects relating to new installations have already been completed.

The newest project will develop guidelines over a three-year period for the application of cathodic protection to existing cables (RP1049). This is the first effort directed toward the mitigation of corrosion of cables already installed (over 100,000 miles of underground residential distribution [URD] cable are now in place). The objectives of this project are to:

- Identify the corrosion mechanisms that can be effectively mitigated by cathodic protection, as well as those that cannot
- Outline measurements required to design an effective cathodic protection system
- Issue guidelines on the selection, design, and installation of a protective system
- Describe tests and maintenance procedures that should be made at regular intervals to ensure proper protection is obtained from the system during its life

A separate guideline will be issued describing postinstallation tests required to determine if the system output is adequate to provide an acceptable level of protection. The Pacific Gas and Electric Co. is the contractor for this project.

The following projects on new systems have been completed: an investigation and status report on concentric neutral corrosion of URD extruded cable (RP747); an evaluation of semicon jacket for concentric neutrals (RP671); and a computer program for determining step-and-touch potentials of faulted URD cables (RP797). Final reports will be available shortly. Since the majority of utilities do not have corrosion engineers to deal with this problem, these final reports should be of value to most distribution engineers. *Project Manager: Bill Shula*

Overhead distribution

A new project with Electro Energy Corp. (RP998) will address the need to develop a rugged, accurate, portable, clamp-on, power factor meter, suitably mounted on a hot line pole for direct line application at distribution voltages up to 345 kV.

Changes in the various loads on a distribution feeder inevitably lead to changes in load distribution, power factor, and voltage gradients along the distribution feeder. These changes contribute to decreasing feeder efficiency. Corrective action can be taken by the proper application of shunt capacitors and regulators and by equalizing load distribution along the feeders. Such corrective action requires the up-to-date knowledge of certain circuit parameter conditions.

Major utilities have developed computer programs or have permanent or temporary instrumentation on their feeders to furnish the up-to-date data necessary to perform the corrective action. Others, without such programs or instruments, need a low-cost, portable device to obtain the necessary data.

Some preliminary work has been done on such a device by the contractor, but certain goals have not been met. As designed, the device is too heavy, consumes too much battery power, and requires a better insulation level for the electric components.

Under this project, the contractor will redesign the electronic circuitry, the current transformer, and the housing and its sealing; construct and test a new prototype; and provide two units for field trials. The prototype units will be field-tested by Southern California Edison Co. *Project Manager: Bill Blair*

OVERHEAD TRANSMISSION

Line design

A 170-page handbook, *Transmission Lines / HVDC to ±600 kV,* contains complete line design parameters for ±600-kV dc lines established by the Bonneville Power Administration (BPA) at The Dalles High-Voltage Test Center and is the final report for RP104. BPA has used these data in designing their proposed second dc intertie line from The Dalles to Phoenix. Preliminary data from the book were also used for the design of the new dc lines in the Midwest.

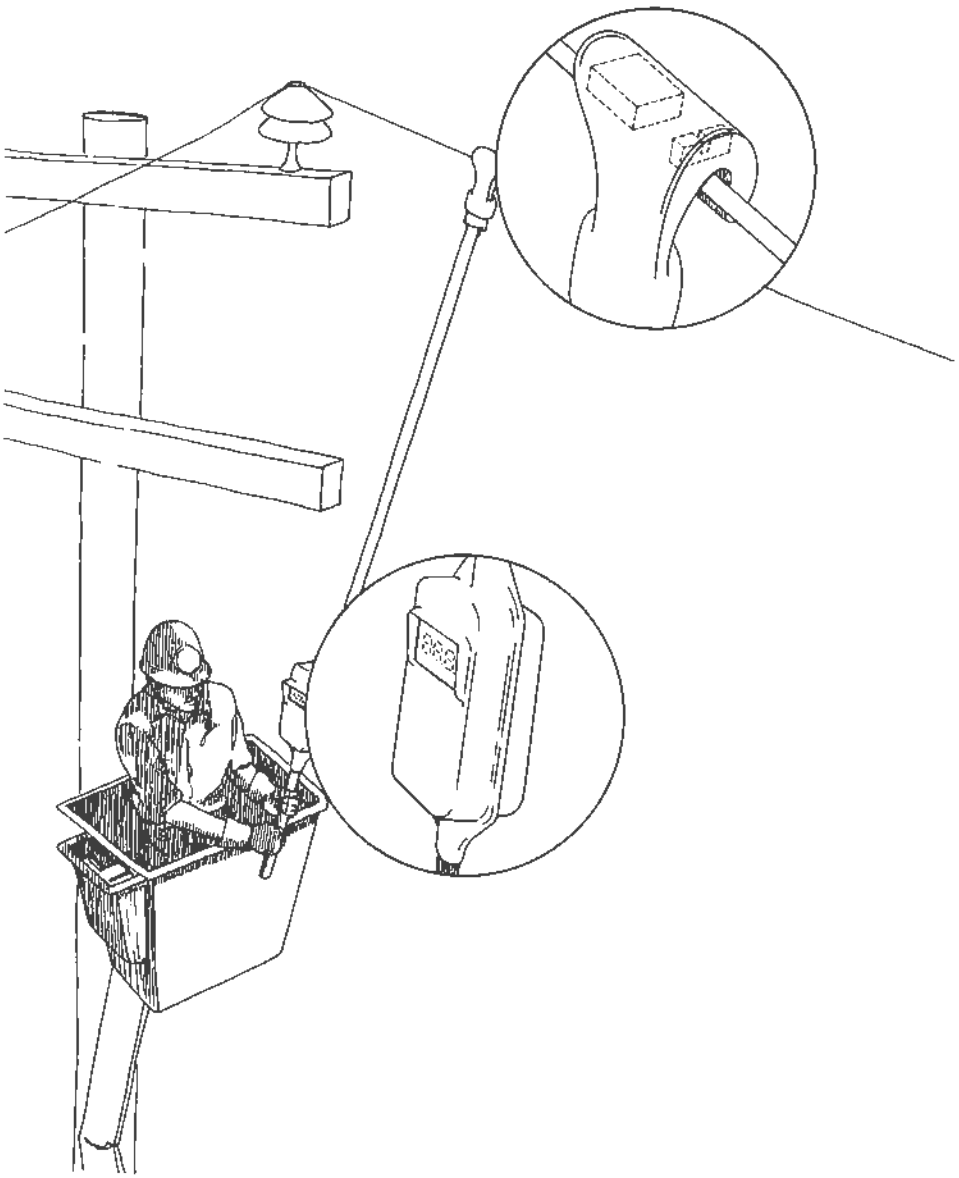
This reference book was issued in February and is available to EPRI members on request. Others may purchase this hardbound book for $17.50 through the Research Reports Center, P.O. Box 10090, Palo Alto, California 94303. *Project Manager: Frank Young*

Environmental effects

Another reference book is being prepared this year in cooperation with the American Gas Association (RP742). AGA and EPRI have combined forces to develop a clear understanding of induced ac potentials on pipelines.

Methods previously used to estimate voltage and current resulted in much higher values than were actually obtained through measurement. This project has developed a new analytic method for predicting voltages and currents induced by 60-Hz electromagnetic fields on both buried and above-

Figure 3 Developmental portable power factor meter contains amplifier and hall device in molded plastic hook and readout near workman's hand. Its accuracy, safety, and light weight are the principal benefits.



ground pipelines. This empirical data approach is much more accurate than the calculatory methods now used.

With the trend toward more joint use of rights-of-way by pipelines and transmission lines, this practical engineering approach will permit both gas and electric utilities to build more joint-use facilities. As a result of this project, both industries will be able to achieve optimum locations for their structures at a considerable savings in rights-of-way. *Project Manager: Frank Young*

UNDERGROUND TRANSMISSION

Installation, maintenance, and auxiliary equipment

As the industry moves to higher power levels and attendant higher conductor operating temperatures in underground transmission cable, the ability to dissipate heat from cable through the backfill (caused by losses) could become a problem to many utilities in the future. When this heat cannot be conducted away, high temperatures result, and a "bakeout" condition occurs during which moisture is driven out of the backfill. Without moisture in the soil, a high thermal resistivity is encountered.

A soil is considered stable when heat is dissipated in such a manner that no net moisture migration occurs. The problem with many soils and thermal sands used today is that they are unstable, and a net moisture transport occurs at low operating temperatures so that the cable must be operated below its normal thermal design limits.

An effort under way at the Berkeley campus of the University of California may provide a means of eliminating unstable conditions and the onset of thermal runaway at higher operating temperatures (RP7841).

Two soil additives are being investigated by the contractor that would either improve moisture retention of the soil, and therefore its thermal conductivity, or promote a condition of soil stability without the need for water.

The present research effort should be completed by June 1977 and may provide utilities with cheaper, more readily available backfill materials from local sources. *Project Manager: Tom Rodenbaugh*

Present methods used to install pipe-type cable impose high costs because of the limited section lengths through which cable is pulled. Every additional cable pull required for the installation of a pipe-type cable means that an additional manhole and associate equipment must be set up. Without more precise knowledge of what pressures the cable is experiencing and the consequences thereof, both utilities and manufacturers have been overly conservative in their approach to cable installation. A project soon to be completed by Power Technologies, Inc., addresses this problem (RP7847).

Tensile and elongation tests for various sizes of cables (with both aluminum and copper conductors) have been made. Determination of friction factors for skid wire materials and cable configurations has commenced. The consequences of sidewall pressures will be experimentally determined on actual cable samples. The theory derived from the experimental and analytic work will be tested on an actual cable pull. The results and cable-pulling guidelines will be published.

Substantial savings may be realized by employing the longer pulling lengths suggested by this project as a result of the reduced number of manholes, splices, and equipment setups required. *Project Manager: Felipe Garcia*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

FUEL PRICE FORECASTS

Two of the most comprehensive long-term fuel price forecasts prepared since the Arab oil embargo have been released by EPRI's Supply Program staff (RP759, "Fuel and Energy Price Forecasts"). The forecasts were developed independently by Foster Associates, Inc., and Stanford Research Institute (SRI) on a regional basis for the period 1985–2000. They cover primary fuels at the point where they first enter the stream of commerce (e.g., coal at the minemouth); fuels delivered to electric power plants; and fuels delivered to representative transportation, residential, commercial, and industrial customers. The studies concentrate on coal, uranium, crude oil, syncrude (produced from coal and oil shale), natural gas, and high-Btu syngas. It should be noted that the price forecasts are the contractors', not EPRI's. Forecasts of electricity prices are not included in the reports.

Prices of coal, the most important fossil fuel for power generation between now and the end of the century, are of particular interest. The two contractors' base case price forecasts for high-sulfur coal delivered to electric utilities in the Middle Atlantic States and East North Central States (prices were developed for all nine census regions) are shown in Figure 1 by broken lines. Also shown is the range of possible prices for each forecast.

SRI forecasts that high-sulfur coal prices will rise slowly between 1985 and 1995—1.3% and 0.8% annually in the Middle Atlantic States and East North Central States, respectively—and then decline between 1995 and 2000 to $\$0.97/10^6$ Btu in the Middle Atlantic States and to $\$0.78/10^6$ Btu in the East North Central States. Foster, on the other hand, foresees high-sulfur coal prices rising steadily between 1985 and 2000—1.6% annually in the Middle Atlantic States and 1.8% annually in the East North Central States. Foster forecasts that by 2000 high-sulfur coal prices will be 24% and 70% higher than SRI's in Middle Atlantic States and East North Central States, respectively. Of course, these prices may not be typical of those faced by an individual utility due to such factors as its mix of coal purchases, the type of escalation provisions in its contracts, different transportation costs, and the specific mines that supply its coal. Nevertheless, the forecasts indicate expected trends within regions.

It is not possible to say which forecast is more likely to be closer to actual values. This is reflected both in the difference between the two independent price forecasts and the range of uncertainty in each forecast. It is very important to point out that both contractors assigned wide ranges of uncertainty to their forecasts. SRI's high (+100%) and low (- 50%) case prices are based only on cost uncertainties and exclude short-term market uncertainties. SRI assigns a subjective probability of 80% that the prices lie between the high and low cases. While the probability is not symmetrically distributed about the expected value, the subjective probabilities of the prices being above the high case or below the low case are each estimated to be about 0.1.

Among the uncertainties of future coal prices are mine health and safety regulations, strip mining laws, federal land leasing policies, water resource utilization policies, and air and water pollution regulations. Because many of these are of a political nature, they are difficult to predict. SRI's high case assumes that most of the uncertainties are resolved so as to increase the price of coal, and the low case assumes that their resolution is in the direction that reduces the price of coal.

Table 1 shows the price ranges that Foster developed for its coal forecasts. The upward movement in coal prices is felt by Foster to be influenced by the world oil price. Coal prices in the extreme case would rise toward the level of oil prices, although parity would not be attained. The downward percentage variation is due primarily to increased mine productivity.

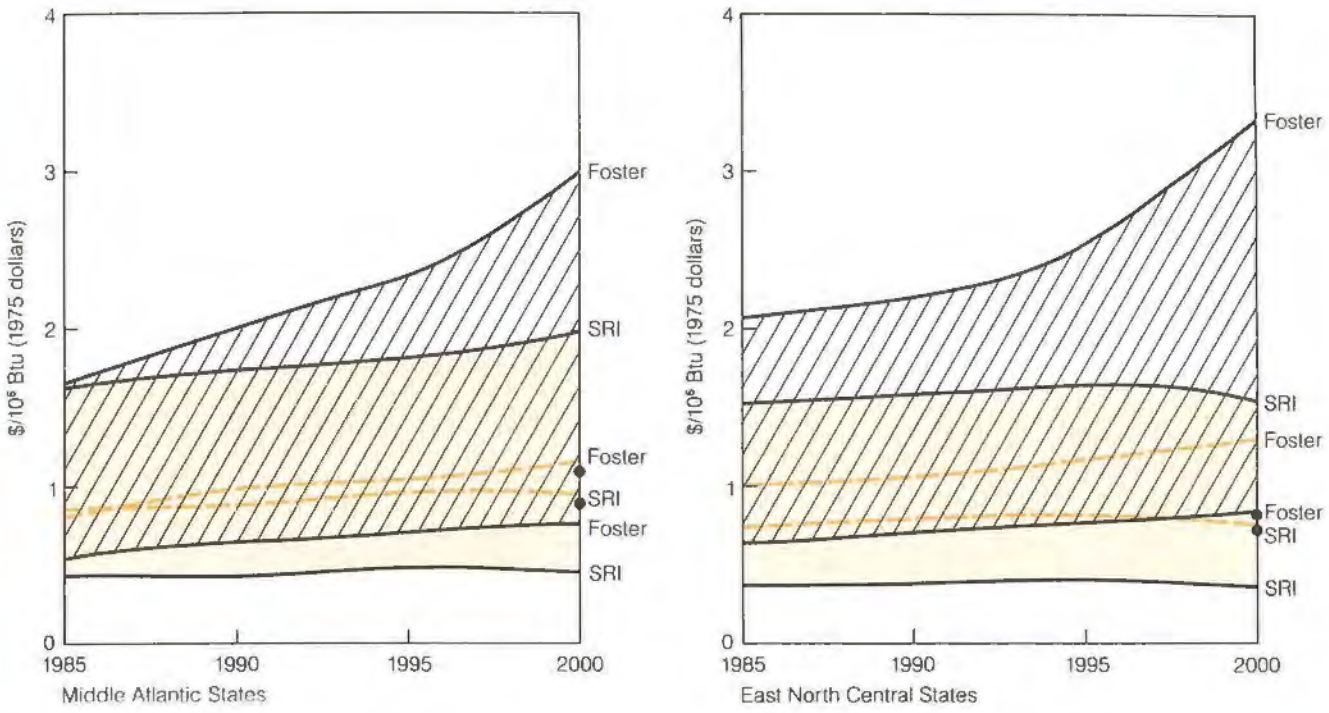
Table 1
PRICE RANGES FOR COAL FORECASTS

	1985	*1990*	*1995*	*2000*
Upward variation	+ 100%	+ 100%	+ 115%	+ 150%
Downward variation	− 35%	35%	35%	35%

The SRI figures shown come from a base case assuming a level of annual production of 2.2×10^9 tons by the year 2000. SRI also analyzed higher and lower production cases. These do not result in greatly different coal prices. Prices resulting from a 72% increase or a 35% decrease in production for the year 2000 are shown by circled points on each side of the expected price. The SRI study reported here draws heavily on coal from western sources. Alternative analyses with more emphasis on eastern coal have also been prepared.

The EPRI Supply Program staff will use

Figure 1 SRI forecasts high-sulfur coal prices will rise slowly between 1985 and 1995, then decline between 1995 and 2000 to $0.97/10⁶ Btu in Middle Atlantic States and $0.78/10⁶ Btu in East North Central States. Foster Associates, Inc., foresees prices rising steadily between 1985 and 2000, placing them at 24% and 70% higher than SRI's forecast by the year 2000 in Middle Atlantic States and East North Central States, respectively. SRI and Foster base cases are indicated by broken lines. SRI's projected prices resulting from a 72% increase or a 35% decrease in production for the year 2000 are shown by circled points on each side of the expected price.



these two studies, as well as the results of other EPRI studies and outside work, to produce EPRI forecasts of fuel prices.

The Supply Program has launched a major study of future coal supply. One of the main goals of the work is to gain a better understanding of the forces causing the uncertainties and to devise better methods of reducing or dealing with these uncertainties. *Project Manager: Thomas Browne*

ADAPTING WHARTON MODEL FOR UTILITY USE

The state of the economy can have a significant effect on energy markets. For instance, as national income and population increase, industrial, commercial, and residential demands for gasoline also tend to increase. More gasoline is needed to supply greater amounts of goods and services to households. Gasoline use increases because the number of automobile drivers rises, and the typical driver can afford to travel more and further. As the price of gasoline starts to rise, capacity tends to expand in the oil refining and extraction industries and gasoline supply tends to increase to meet demand. These interactions have been modeled by analysts studying the markets for gasoline and other energy forms.

Conversely, the state of the energy markets may have a significant effect on national income. A number of examples can be cast as questions. If the relative price of energy in the U.S. continues to rise, how much more inflation and unemployment may be expected? Will the large increases in relative energy prices of the last few years reduce appreciably the total amount of goods and services the U.S. economy can produce at full employment? And tied to the first two questions, to what extent will the rise in relative energy prices impact the long-run rate of growth of energy and, specifically, electricity demand?

Answers to these questions are critical to a proper understanding of the issues and to the planning of appropriate national and industrial policies. It is only recently that serious attempts have been made to model formally the effects that energy markets have on the national economy.

RP440 is an attempt to model energy-economy interactions in detail. In this project, Wharton Econometric Forecasting Associates is modifying and expanding its Annual Industry Model, which has been used for some years to provide forecasts of national income, prices, wages, interest rates, industrial activity by sector, and other information of importance to business planners. The Annual Industry Model was built on the foundations laid by Professor Lawrence Klein, president of Wharton EFA, one of the country's leading econometric modelers, and a pioneer in the field. Econometric methods involve specifying a rea-

sonable and theoretically well-founded behavioral model and then statistically estimating the parameters of the model, using historical data.

The expansion of the Annual Industry Model in RP440 has consisted of a number of steps. The first efforts were to modify the input-output table of the model. An input-output table consists of a matrix, each column of which displays the recipe of inputs needed for a given industry per unit of output produced. The original 47-sector input-output table was expanded to 59 sectors to allow important energy-using and supply sectors to be displayed. In addition, by using econometric methods, Wharton has estimated how the input-output coefficients change with wholesale price changes.

Wharton's second major effort in this project has been to construct satellite models of important energy-producing and -consuming industries. These models provide more detailed information about individual energy-producing sectors than was available in the long-run annual model. Econometric satellites have been constructed for the cement, coal, and steel industries.

Professor James Griffin of the University of Pennsylvania has developed a novel methodology for building satellite models that allows the input-output coefficients in a column of the matrix to depend on relative input prices. Using this approach, based on a synthesis of engineering and econometric methods, he has constructed an electric utility satellite.

A workshop was held last January 4 and 5 at EPRI headquarters in Palo Alto to review progress with the Wharton Annual Energy Model and to suggest scenario runs that EPRI and the electric utility industry would find informative. Prominent representatives from the industry were present to advise on the scenarios.

At another workshop, held at EPRI in April, Wharton presented the output from its expanded model projected to the year 2000. Included were the results obtained from a limited number of scenario runs to test the effect on the national economy of significant changes in energy markets. *Project Coordinator: Stephen Peck*

TRACKING AIRBORNE POLLUTANTS

The transport and interactions subprogram is one of the major segments of the Physical Factors Program of EPRI's Environmental Assessment Department. Its main goal is to define the nature of pollutant transport within the environment and to identify the physicochemical reactions that occur during transport. Such information serves primarily to clarify the ultimate fate of pollutants and thereby is an important element in the overall goal of the Environmental Assessment Department, which is to assess the impact of energy production on materials and living things, particularly on humans.

Within the subprogram, nine research projects are being funded at over $2 million in 1977. Five of the studies are being conducted by private research organizations; the remainder by universities and state organizations. Emphasis in these studies is on atmospheric pollutants derived from coal-burning power plants. For the next few years, emphasis will continue to be on such airborne pollutants; however, research is increasingly being directed toward study of pollutants in terrestrial and aquatic environments and on fuels other than coal.

At present, the main focus of the subprogram is on sulfur species in the atmosphere. Much of the research centers on the $5.5 million Sulfate Regional Experiment (SURE, RP862), which is designed to relate regional concentrations of secondary pollutants in the atmosphere (sulfates) to local emissions of a primary precursor (SO_2). While SURE focuses on sulfur oxides, it will study a number of other pollutants, such as nitrogen oxides, particulates, and trace elements. SURE, which is now under way, involves extensive ground and air monitoring of pollutants over the entire northeastern U.S. for a two-year period. The monitoring data, along with emissions data, will provide the basis for assessing the electric power industry's contribution to ambient levels of secondary pollutants.

In addition to SURE, a number of other projects are directed toward studies of sulfur compounds in the atmosphere. One on plume conversion rates in the SURE region (RP860) involves research on SO_2-sulfate transformation in plumes from both oil- and coal-burning facilities. Another, on dry deposition in the SURE region (RP938), is aimed at assessing the significance of deposition of dry pollutants, especially of sulfur species.

Recent work on the determination of feasibility of ozone formation in power plant plumes (RP572) has demonstrated that ozone is not being formed in amounts exceeding that in the ambient atmosphere. The presence of high ozone previously reported by other investigators, therefore, is not universal. In another project on effluents from coal-fired power plants and their interaction with the atmosphere (RP330), findings suggest that the use of an electrostatic precipitator considerably affects particle size distribution of matter emitted from stacks.

Not all subprogram studies focus on stack-emitted pollutants. A project on airborne monitoring of cooling tower effluents (RP484) is studying salt drift from a cooling tower that uses brackish water, and one on atmospheric effects from waste heat dissipation at power plant cooling lakes (RP578) is assessing any inadvertent weather modification that might arise from use of a large cooling lake.

With a sulfur program well under way, efforts in the subprogram are being directed to new problem areas. Future work will focus on four areas of environmental concern: formation of nitrogen compounds in the atmosphere, physical chemistry involved in the formation of acid deposition and in inorganic-organic atmospheric reactions, and contamination related to disposal of solid waste, particularly ash. In all these studies, the ultimate goal is to identify the industry's contribution to the distribution of potential contaminants in the environment. *Program Manager: Ralph Perhac*

IN-PLANT POWER GENERATION

Mathtech, Inc., recently started a 20-month research project (RP942) aimed at constructing models that will forecast in-plant electricity generation in the industrial sector. The share of self-generated electricity in manufacturing has decreased from 25% in 1954 to 14% in 1971 (83×10^9 kWh). The project is based on the premise that this decline reflects rational decisions. To forecast the future meaningfully, there must be an understanding of the motivation for these decisions.

Technology exists for the joint production of process steam and electricity at industrial sites, but major uncertainties are boiler technology, availability of fuel sources, effects on air quality, willingness of industry to risk investment, reliability, and actual efficiencies that can be achieved. A number of federal agencies and independent energy researchers are advocating a shift back to in-plant generation. Thus, the future of self-generation is unclear, with some investigators foreseeing a rapid reversal of past trends and others predicting continuation or stabilization.

For technological reasons the largest potential impacts on utility loads would occur in four industries: paper and allied products, chemicals and allied products, primary metals, and petroleum refining. RP942 will aim at developing behavioral models that will

be used to produce conditional forecasts of the share of electric energy produced in-plant for these four industries. A fifth category will include the in-plant generation by the remaining manufacturing sector. Special concern in this category will focus on identifying, if possible, areas of significant future self-generation.

The models will be based on the economic theory of the firm along with the extension of probabilistic choice theory. A number of engineering cost studies of the potential for in-plant generation have been completed. These studies include detailed treatments of the technical characteristics of cogeneration and identify specific situations that are potentially attractive for the future joint production of steam and electricity. The studies will provide important inputs to the development of behavioral models that will also include structural and institutional characteristics of the particular industries. By combining the technical information contained in the engineering studies with the behavioral approach, the models will attempt to identify the degree to which future in-plant generation might actually be employed in contrast to the present engineering-based studies, which estimate an upper limit on the potential for in-plant generation.

Dynamic industrial demand models

Economics Research Group Ltd. (ERG) has submitted the final report of Phase I of their project on energy-conserving technological change in forecasting manufacturing usage (RP683), which will be published as an EPRI interim report in the near future. The objectives of this study were twofold: to model the derived demands for factors of production (e.g. labor, capital, energy, and other materials) where the factor markets are viewed as being in general disequilibrium; and to examine how the firm utilizes research and development as a factor input in its attempt to minimize current and future costs of production. The Phase I report indicates substantial progress toward these goals. Meeting either of these objectives will significantly improve the state of the art.

Most existing models of industrial demand for energy can be viewed as based on either of two assumptions: (1) that firms are able to adjust completely, with no cost, to changing prices and other exogenous inputs within one time period (one year, usually); or (2) that there are costs of adjustment, but the size of these costs is independent of the speed at which the changes are made. Both of these models suffer from several serious drawbacks. First, it is unlikely that firms are able to adjust their factor inputs to the desired levels within one period. Second, increasing the speed of adjustment probably incurs substantial costs. Third, models that view the world as always being at long-run equilibrium ignore the adjustment process itself. As a result, forecasts based on these assumptions could provide incorrect and misleading results on the nature of industrial response to exogenous shocks (e.g., price or output changes). In addition, the long-run equilibrium analysis would be unable to address itself to such questions as: how long it takes firms to adjust to the new, higher energy prices; whether declines in oil imports are temporary or permanent; how investment incentives affect the speed of adjustment; whether higher energy prices increase or decrease unemployment. To address these issues, one must model the nature of the disequilibrium adjustment and the costs of adjustment.

Also, in existing literature the process of technological change is represented simply as a response to the passage of time. Specifically, the models do not consider the accumulation of knowledge as a process built into present and future planning strategies and subsequent company decisions. As a result they cannot explain that the rate of technological change fluctuates over the business cycle, that technical change affects each factor of production at different rates and perhaps in different directions, and that policy changes influence the rate of technological progress. *Project Manager: Larry Williams*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

THERMAL–MECHANICAL ENERGY STORAGE

In spite of utility need for energy storage, technical and economic uncertainties have so far prevented the construction of the first commercial plant. During the next five years the thermal-mechanical energy storage (TMES) subprogram will evaluate the prospects and accelerate the commercialization of underground pumped hydro (UPH), compressed-air storage (CAS)–combustion turbine systems, and sensible heat thermal energy storage (SHTES). These technologies have significant promise for near-term applications. Utility involvement at the earliest possible phase and close cooperation with ERDA's Electric Energy Systems and Energy Storage divisions will be crucial to the success of the program.

Feasibility studies

Feasibility studies have been carried out for the three near-term technologies. One such feasibility study on a conceptual design for a pilot/demonstration compressed-air storage facility employing a solution-mined salt cavern (RP737) was carried out by General Electric Co., United Engineers & Constructors, Inc., and Fenix and Scisson, Inc. (The final report for this project will substantiate the technical and economic potential of CAS in salt.) Similar studies were carried out for ERDA on CAS in mined cavern and aquifer.

Another project that will provide input to the CAS evaluation is an activity being managed by EPRI with funds provided by the Kansas Utilities Research Study Committee. The objective of the program is to assess the potential of CAS in Kansas. The first phase is an assessment of the applicability of Kansas geology to CAS and planning and cost-estimating a site exploration and qualification program. This should be completed by the end of the year.

These studies and others assessing CAS in mined caverns and aquifers and UPH identified the following areas that are critical for reducing the uncertainties perceived by utilities.

- Greater understanding of the pressure and temperature cycling in salt, rock, and aquifers
- Optimizing methods for construction of underground chambers
- Developing modified equipment designs, such as high-head, single-lift, reversible pump turbines for UPH and high-pressure turbines and combustors for CAS
- Developing improved heat exchangers for SHTES that use secondary loops
- Integrating SHTES concepts into power plant designs

The preliminary studies have also concluded that the remaining uncertainties would be best addressed in a preliminary engineering design study that could provide utilities with a firm foundation on which to base a decision for a demonstration plant.

Preliminary engineering design for CAS and UPH

An RFP for preliminary engineering designs of CAS and UPH was issued jointly by EPRI and ERDA and the responses are now being evaluated. The lead utilities and technologies being addressed are:

Lead Utility	*Technology*
Potomac Electric Power Co.	CAS (mined cavern) and UPH or UPH alone
Public Service Indiana	CAS (aquifer)
The Cincinnati Gas & Electric Co.	CAS (existing limestone cavern)
Middle South Services, Inc.	CAS (salt)
Commonwealth Research Corp.	UPH

Start of work is anticipated by mid-1977 with design studies expected by late 1979.

The preliminary design studies are expected to better define technical and cost uncertainties (both subterranean and surface), establish broadly applicable analytic and design methods, and identify R&D needed to advance the first and following generations of thermal-mechanical energy storage systems.

If these studies produce satisfactory results, it is anticipated that EPRI could set priorities for any R&D required to minimize technological uncertainties and that a participating utility could assemble the information required for the detailed design of a demonstration-scale storage project. Further, a broad cross section of EPRI members will gain an insight into the methodology required to establish the technical and economic feasibility of a technology with some site-related aspects.

Thermal energy storage

SHTES has been identified as having the potential for technical and economic feasibility in the near term. However, a specific SHTES concept has not been identified as having a clear edge. Hot oil storage, saturated water storage (above or below ground), heat transfer scale, and perhaps even pebble bed heaters need further study on a common technical/economic basis. In addition, the implications of SHTES's having to integrate a thermal store with a specific baseload power plant rather than the utility network have not been adequately addressed. The first step in the SHTES project is an in-depth comparison of the principal concepts.

EPRI and NASA, Lewis Research Center (acting through an interagency agreement with ERDA) have initiated a joint activity to address the questions discussed above. An RFP was issued in February 1977, and the study is expected to be completed by February 1978.

Supporting R&D for advanced concepts

In addition to the major projects, the TMES subprogram also includes efforts to support the major projects with specific studies and experimental efforts on limiting technical problems and to investigate thermal-mechanical energy storage concepts that could result in significant advances over the first-generation technologies. One prime candidate in this category is an advanced version of compressed-air storage in which compressed air and the heat of compression are stored together. This concept eliminates the need for the combustion of oil to reheat the stored air on discharge. Another group of advanced CAS concepts addresses the integration of CAS with alternative heat sources, such as a fluidized-bed combustor, a coal gasifier, or a coal-fired heat exchanger. *Project Manager: Joseph Pepper*

FLUIDIZED-BED COMBUSTION

The design of a utility steam generator requires information about the fuel to be burned so that features that are fuel-property sensitive can be optimized.

For a coal-fired steam generator, the grindability and moisture content of the coal must be known in order to select the pulverizers. The reactivity of the fuel (its ease of ignition and the rate at which it burns) is another factor in pulverizer selection. Reactivity is also a criterion in sizing the furnace, but the major factor is the behavior of the coal ash in the pulverized-coal flame. At the high temperature reached in the flame, the ash melts. The furnace is designed so that ash particles are solidified before they are carried through the convective heat transfer surfaces. Because pulverized-coal boilers are so coal-property sensitive, they must be custom-designed for the "worst" coal anticipated for a given application.

By comparison, a fluidized-bed combustion (FBC) boiler is designed to prevent the melting of the coal ash. (The reason will be discussed later.) The grindability of the coal fed to a fluidized-bed boiler is not important; the coal is not pulverized but only roughly crushed (top size, ½ in).

An FBC unit is shown in Figure 1. At the bottom of the furnace is an air distributor. Particles of limestone and coal ash form a fluidized bed when a sufficient flow of air is passed through the air distributor. A fluidized bed has some liquidlike properties (even though the particles remain solid). For example, a fluidized bed exerts a hydrostatic pressure on its container and has a measurable viscosity.

Coal can be burned in a fluidized bed when the temperature of the bed is above the coal ignition point, about 1000°F for most coals. The heat released by coal combustion is transferred almost instantly to the limestone and coal ash particles that form 99+% of the fluidized bed. Boiler tubes, located in the bed, cool the hot bed particles. Heat transfer is so rapid that the coal particles never exceed the bulk ash melting temperature. Since two of the most important coal properties, grindability and ash fusion, do not affect the performance of an FBC boiler, one design could serve most of the electric utility industry. This is one of the major incentives in EPRI's program to develop an FBC boiler. Before an FBC system can be built, a number of technical problems must be resolved.

Figure 1 Schematic of a fluidized-bed boiler.

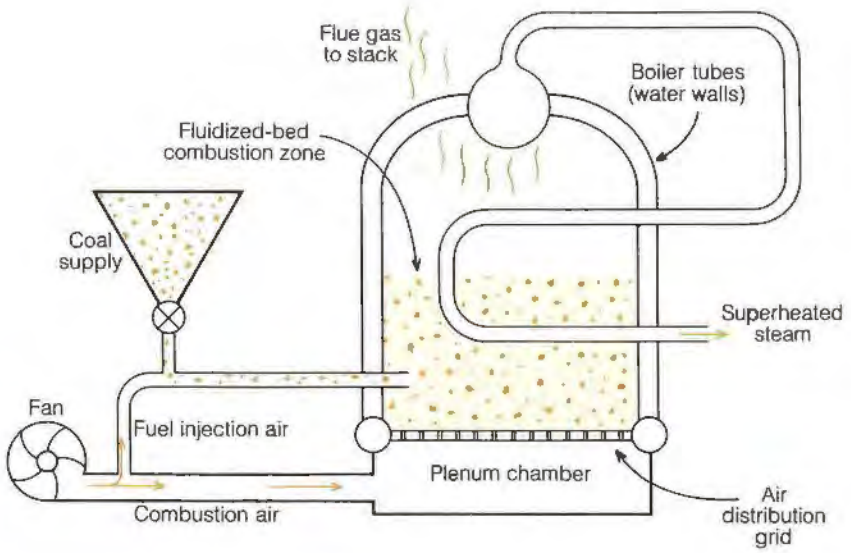


Figure 2 illustrates the objectives of R&D now under way to solve the technical problems. Beyond the R&D listed, major ancillary components must be developed for FBC boilers, such as a system to split coal into a number of equal streams.

Sorbent consumption

Limestone is used as the bed material when SO_2 control is required. (When SO_2 need not be controlled, the coal's own ash can provide the fluidized bed.) Theoretically about 160 lb of limestone would control SO_2 emissions for each ton of a 3% sulfur coal. From two to three times this quantity actually has been needed in most experiments, and the reason for this is being explored (RP720). We have found that calcination conditions influence the capacity of a limestone particle to absorb sulfur. If limestone is calcined in an isolated zone in the FBC boiler, a high CO_2 partial pressure, which research indicates is desirable for calcining, could be achieved.

Less limestone is needed if the particle size is reduced (RP719). If the particles that carry over are captured in a cyclone and recycled to the bed, the limestone can absorb more SO_2. Tests in the United Kingdom showed that this technique could reduce sorbent needs to near theoretical.

In 1969 it was discovered that small quantities of common salt increased the capacity of the limestone. While this was an interesting lead, the use of salt in a utility boiler would not be desirable. The University of Maryland is attempting to determine why salt works so that other additives can be developed to achieve the same goal (RP837). With ERDA funding, Argonne National Laboratory is also doing some salt experiments. Both research groups now believe that the effect of salt on the ultimate lime pore structure is significant.

Figure 2 FBC research, development, and demonstration plan. EPRI's, ERDA's, and EPA's fluidized-bed boiler R&D projects are coordinated. The objective of the research is the operation of a demonstration plant by 1983.

Problem	Approach	Project Objective
Sorbent Consumption *Requirement:* Reduce limestone needs to CaS<1.5	• Controlled calcination	Increase porosity and activity (high CO_2, partial pressure)
	Reduced particle size	Produce very small limestone in situ; increase reaction surface (hydration)
	Carryover recycle	Increase residence time (develop technique for fine recycle)
	• Additives	Increase activity (determine cause for NaCl effectiveness)
	Proper stone type	Select most reactive limestones (chemical/physical characteristics)
	• Synthetic sorbents	Develop superior regenerable sorbent (reduce attrition and activity loss to <0.01%/cycle)
	Limestone regeneration	Regenerate with coal; prevent loss of activity (short residence time)
	• Bed cleaning	Maintain chemical purity, remove erosive particles (e.g., screening, air classification, magnetic separation)
Combustion Efficiency *Requirement:* Increase combustion efficiency to 99+%	Freeboard design	Define required combustion gas residence time
	• Carbon-burnup cell	Verify concept; develop effective feeders
	Solids mixing and circulation	Define proper tube spacing and height from air distributor (improve gas-solids contract)
	• Fuel feed and distribution	Develop techniques for metering coal and injection into bed (reduce complexity and improve performance)
Boiler Control *Requirement:* Change load at 5%/min; prevent tube overheating	Heat transfer surface arrangement	Select arrangement for reduction of heat transfer surface with reduced airflow
	• Air distributor design	Permit load reduction without defluidization
	Sectionalized air-fuel supply	Permit load reduction without bed material removal
	Air preheat control	Design for constant air preheat
	• Review existing controls and modify	Evaluate state of the art (Rivesville)
	• Model dynamics	Produce dynamic model of Alexandria and Rivesville
Materials of Construction *Requirement:* Select alloys and/or tube arrangements for 15-year minimum life	• Alloy evaluation	Establish useful life of important boiler alloys
	Improve solids mixing	Minimize local reducing zones
	Heat exchanger arrangement	Prevent jet impingement
	New alloys	Design corrosion/erosion resistant alloys
Waste Handling *Requirement:* Develop environmentally acceptable and economic methods for disposal or utilization of spent sorbents	• Landfill	Establish techniques to prevent mobility (gross movement and leaching)
	• Agricultural use	Determine value for pH control; determine calcium and sulfur source
	• Industrial use	Develop useful construction materials
Undefined System Design Requirements *Requirement:* Cost-effective design and reliable operation of utility-scale FBC steam generator (system integration and scale-up)	Conceptual design study and preliminary cost estimate	Establish design-specific development tasks
FBC Demonstration Plant		

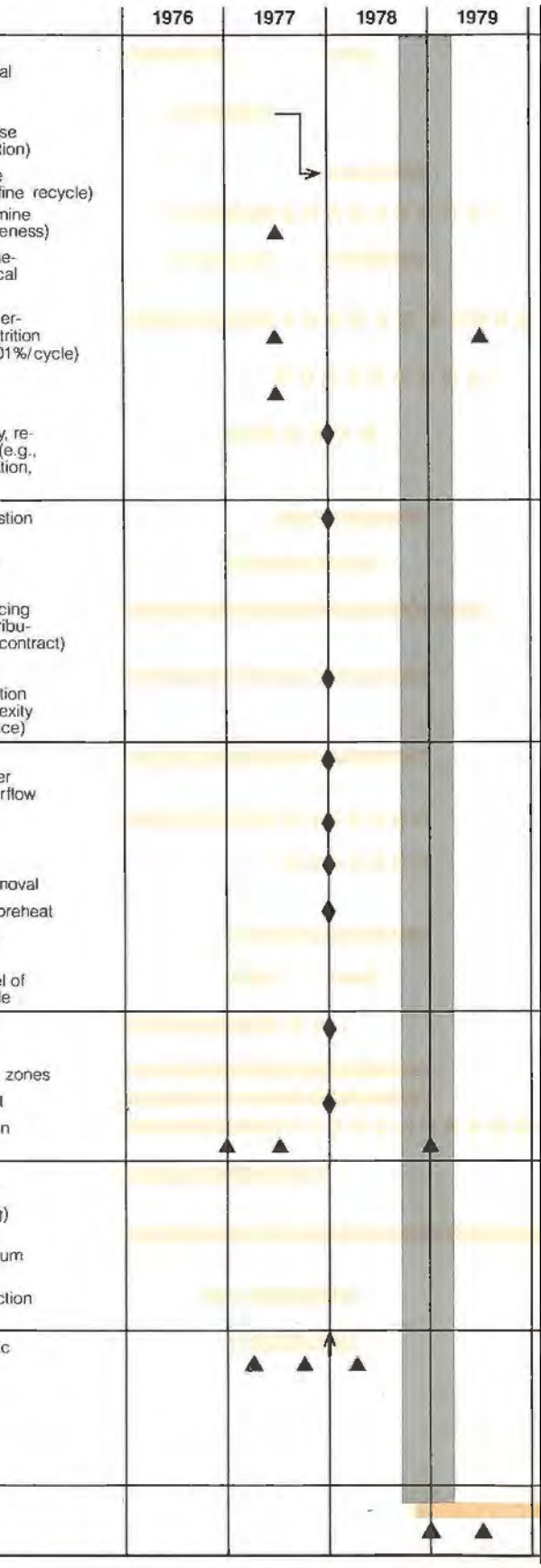
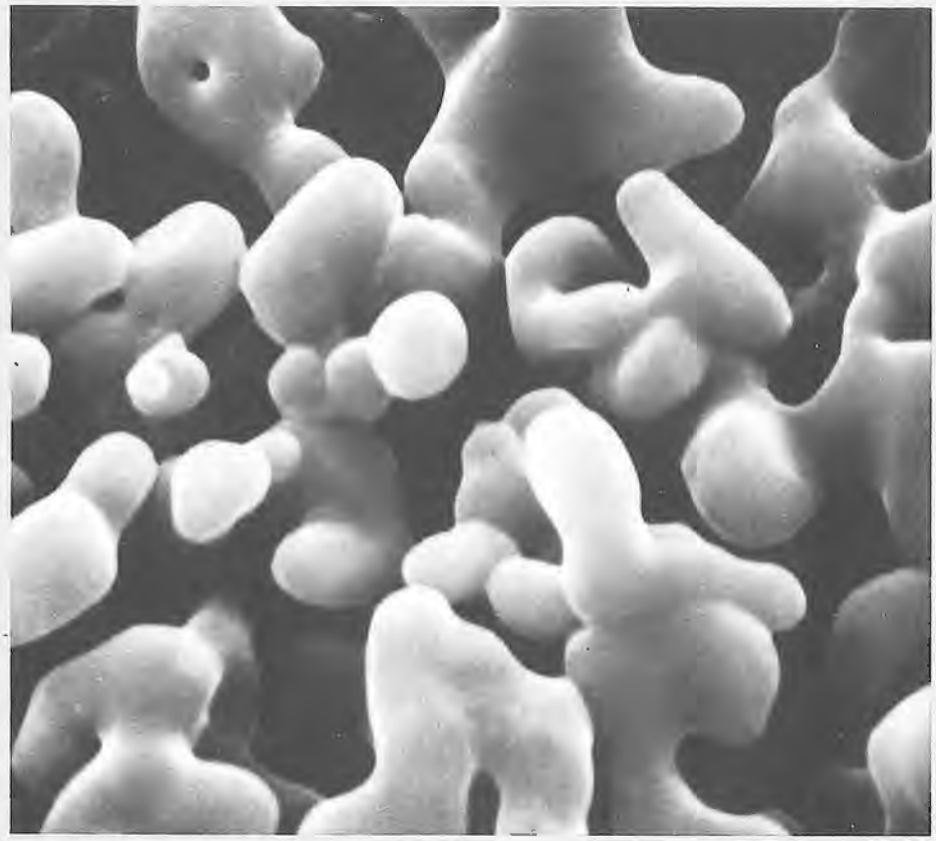
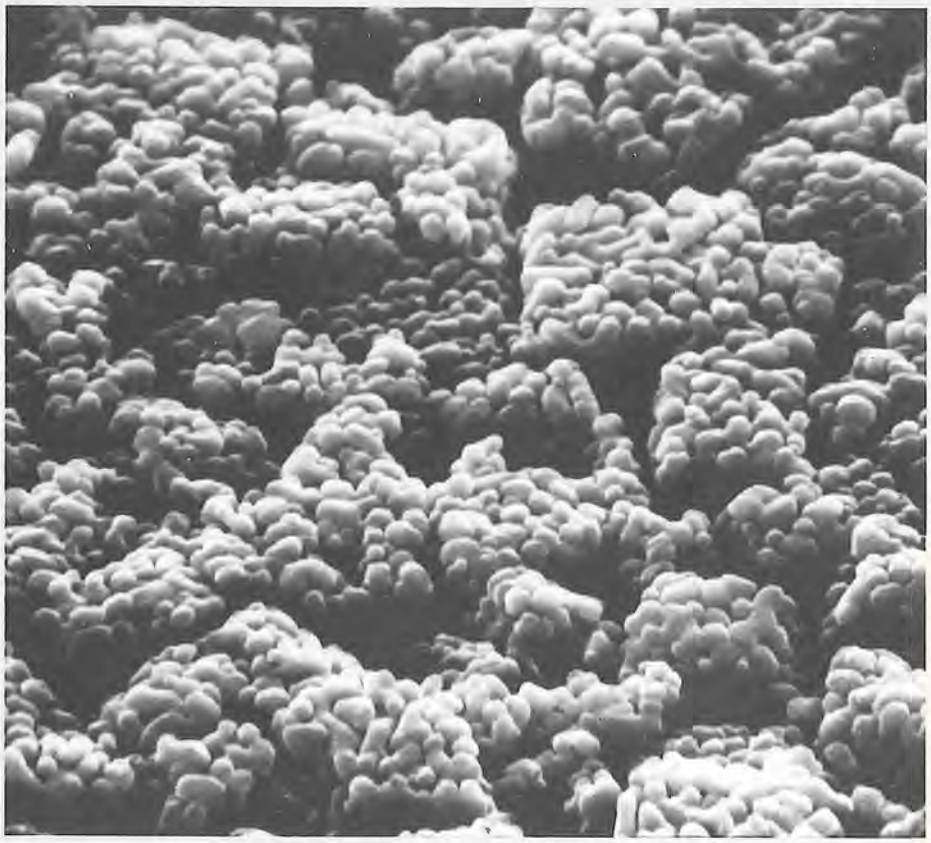


Figure 3 Reagent grade $CaCO_3$ calcined, 915°C, 1 h. No NaCl added (top). Reagent grade $CaCO_3$, plus 1% NaCl calcined, 915°C, 1 h (bottom).





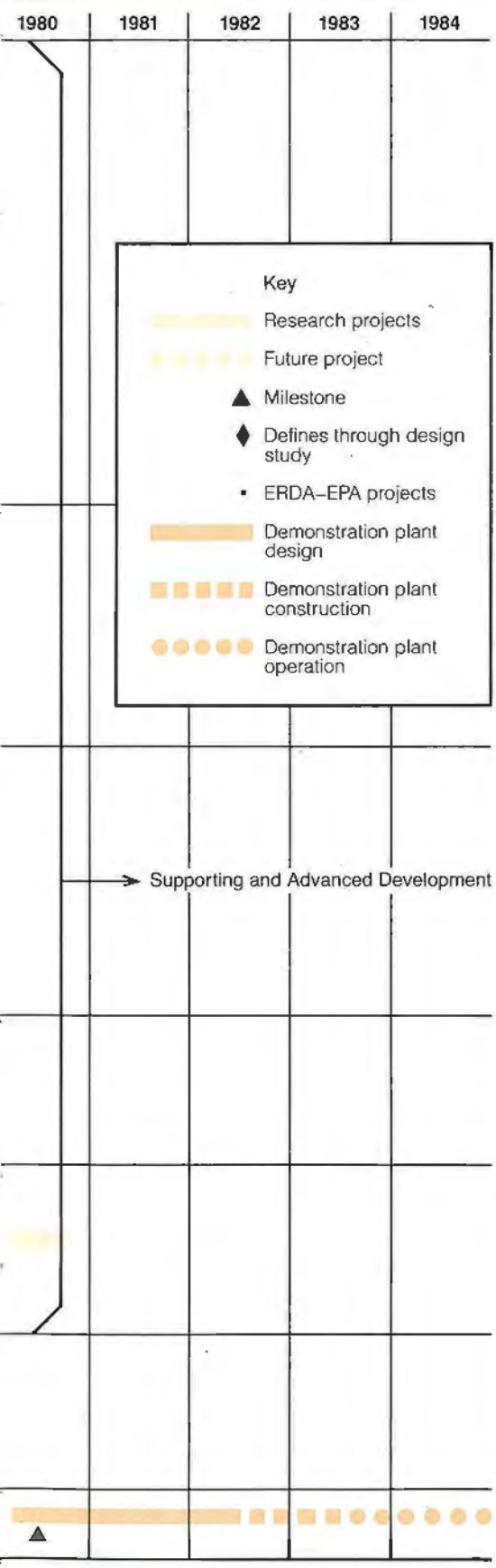


Figure 3 shows how salt changes a lime particle. Argonne is now attempting to determine if the salt can be locked into the lime particle to prevent subsequent tube fouling and corrosion. Although this important work is being done with ERDA support, the results of the work are available to EPRI and to EPRI contractors. In an agreement recently signed by EPRI, ERDA, and EPA, results are exchanged as quickly as they are reported. The research contractors have been encouraged to communicate among themselves, regardless of sponsorship.

An attempt is being made to characterize limestones to determine which will be most effective in an FBC boiler (RP721). Interestingly, high-purity limestones, desirable for wet scrubbers, have shown worse performance in FBC tests than low-grade stones. This may be important because it gives FBC an important cost advantage; low-grade limestones of about the right size are widely available as a by-product of aggregate quarry operations.

Theoretically, a regenerable synthetic sorbent could be used to replace limestone (TPS 75-603). Our staff estimates show that unless attrition losses are very near zero, synthetic sorbents would be far more costly than limestone (the cost ratio is ~200:1).

Argonne is attempting to develop an attrition-resistant synthetic sorbent. Exxon Research and Engineering Co., with support from the National Science Foundation, is also studying synthetic sorbents, and both projects are being followed. Argonne is also doing experiments on regeneration of limestone and the results are very encouraging (10 cycles for the limestone with reasonable reactivity retention and ~8% SO_2 in the regenerator off gas, which is a practical concentration for reduction to sulfur). The process Argonne has been studying involves a short residence of lime particles in the high-temperature regenerator. EPRI will be doing an economic evaluation of regeneration in 1977 and plans to support development if the economics are favorable.

If regeneration is required to make FBC meet the utility industry's cost requirements, one other system must be developed: a system for removing coarse coal ash particles from the fluidized bed so that the lime content remains high. When a high-ash coal is fed to a fluidized bed of limestone, ash particles remain after the coal has burned away. Over a period of time, the ash content of the bed increases and reduces the sulfur-capture efficiency. To control SO_2, the ash-laden bed must be purged while fresh limestone is added. Still-active limestone is thus wasted to control bed ash content. However, the coal is fed at a top size of ½ in, while the limestone top size is ⅛ in. This size difference might be exploited to make a separation between ash and limestone, but a workable system has not been developed. Design studies now under way by Foster-Wheeler Energy Corp., Babcock & Wilcox Co., and Combustion Engineering, Inc., will indicate what development is needed. The goal of these studies, which are under TVA contracts and supported by TVA, ERDA, and EPRI, is to prepare a preliminary design that could solve some of the problems shown in Figure 2. The major issues are discussed below.

Figure 4 Construction of a 36-ft² fluidized-bed development facility will be completed in September.

Combustion efficiency

The same characteristics that make it possible to envision a universal FBC design (coarse coal, no high temperatures) also reduce the rate at which coal burns. High combustion efficiency required for utility boilers, 99+%, is not achieved in an FBC system unless the system is carefully designed. Figure 2 indicates that current work is sparse. EPRI is awaiting the completion of the FBC development unit at Alliance, Ohio (scheduled for startup in September, RP718). This unit (Figure 4) is 36 ft² in cross section and will be used first to tell how to design the freeboard (the space between the top of the fluidized bed and the furnace outlet). At Alexandria, Virginia, ERDA's 8-ft² process development unit has been converted to a carbon-burnup cell, which is basically a secondary combustor fired with carryover recycled from the main FBC systems. Also at Alexandria, tests in a 1-ft² unit in 1969 and 1970 showed under what conditions

99+% combustion efficiency could be achieved.

The key to high combustion efficiency is proper hardware design. An experimental tool has been developed that can be used to determine how rapidly coal will mix in the fluidized bed (RP315). This in turn will be used to determine how many coal injectors are needed and how they should be designed.

Boiler control

An FBC boiler captures sulfur best when the bed temperature is 1500°F–1600°F. This adds a new parameter, temperature, to be controlled by the combustion control system, which also poses a difficult problem for the designer. Predictive tools are being developed that should permit the design of a self-regulating system, that is, the bed temperature will remain constant as the firing rate is varied (RP315, RP525). A number of mechanical techniques that can be used to keep temperature constant are being considered in the design studies, but self-regulation is the preferred solution.

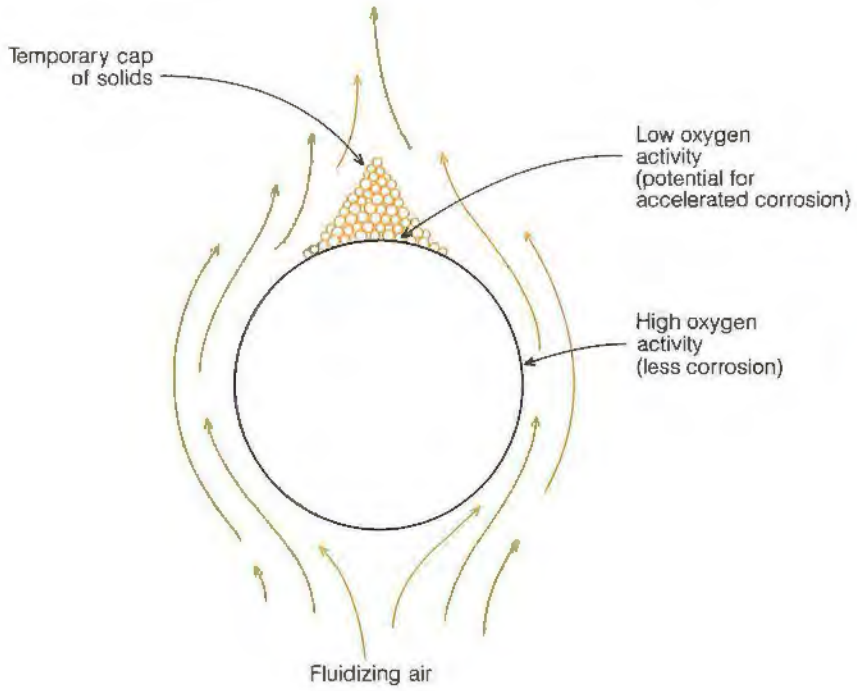
Construction materials

In 1971 EPA sponsored a major FBC R&D program in the United Kingdom. One of the tasks was a corrosion study at Stoke Orchard. These relatively brief tests (~500 h) did not show corrosion rates to be intolerable; but neither were they trivial. Other tests by the Bureau of Mines at Morgantown, West Virginia (also EPA-sponsored), and at Combustion Power, Inc. (ERDA) showed poor corrosion resistance of a number of normally useful alloys. The Bureau's results were not published, but EPRI was given access to the raw data and analyzed the results (ASME 76-WA/CD-4).

The most thorough examination of FBC materials is being done under RP388. The preliminary results have caused some concern about the corrosion of the tube materials. Under RP980 EPRI will perform a critical test of FBC materials. There is reason to be optimistic: EPA's 1971 experiments and RP388 were carried out in the same 1-ft² test rig but under markedly different conditions, the EPA test conditions being closer to EPRI's current concept of the best operating conditions. Figure 5 shows why corrosion occurs at the top of an FBC tube. A temporary cap of solids resting on a horizontal tube results in very low oxygen activity and penetration of sulfur into the metal. Under RP525 a tool has been developed that measures the residence time of this cap, and as the firing rate (Btu/h/ft² of plan area) is increased, the cap residence time is decreased. In RP388 the firing rate was only 200,000 Btu/h/ft², but in RP980 it will be near 10^6 Btu/h/ft², which is a more practical value (the value in a pulverized coal boiler is ~2×10^6 Btu/h/ft²). Under RP1028 EPRI will be doing a screening assessment of a design concept in which superheat and combustion are separated so that there can be no corrosion. (There is no evidence of fireside corrosion of water walls in an FBC unit.)

It is concluded that FBC boilers will replace pulverized-coal boilers equipped with scrubbers only if their performance and economics are superior. There are a number of inherent advantages of FBC, but a system that the utilities can buy with confidence has not yet been developed. Most reports in the nonscientific press tend to ignore the problems needing solutions. Reports in the scientific press are generally very specialized, which also does not assist a balanced engineering judgment. The design studies and the FBC development facility should provide some key analyses. *Program Manager: Shelton Ehrlich*

Figure 5 A horizontal superheater tube shows accelerated attack at the top of the tube. This may be related to the "lee" cap of solids that temporarily blocks oxygen flow to the hot surface.



R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

ASSESSING USE OF THORIUM FUEL IN PWRs

Light water reactors (LWRs) using the uranium fuel cycle have become the mainstay of commercial nuclear power development in the U.S. and in many other countries. This role for LWRs was not the one envisioned at the start of nuclear power commercialization in the mid-1950s. At that time, there was fairly general acceptance of the desirability of installing fast breeder reactors (FBRs) in as expeditious a time frame as possible, and the role of LWRs was expected to be only as a seed for the FBRs. That this has not happened so far and may not happen for the next few decades has posed some painful questions for nuclear power development in this country.

A basic characteristic of our commercial nuclear power development based on LWRs is that it has a finite lifetime, one strictly dependent on the amount of uranium available from the ground. In addition, the recent increases in the price of uranium, coupled with those in plant costs, have put increasing pressures on the competitiveness of LWRs as presently operated—using the once-through uranium fuel cycle. Thus, the promise of nuclear fission power as an unlimited source of electric energy is neither at hand nor expected in the next two or three decades.

An alternative fuel resource for nuclear power is thorium, which on being irradiated in a reactor is converted to uranium-233, a highly efficient fuel. Utilization of thorium has the potential of extending the life of our available uranium resources because thorium increases the amount of energy extracted per mined ton of our uranium fuel resource. This potential of thorium, however, can only be realized if the reprocessing of thorium-based fuel is in place to recycle the uranium-233 produced.

Various thermal reactor designs using thorium-basad fuels have been developed. Most prominent among them are the high-temperature gas reactor (HTGR), the light water breeder reactor (LWBR) and the molten salt breeder reactor (MSBR). None has yet reached the commercial stage. In fact, it appears that successful introduction of a new reactor system into commercial practice is a task not easily financed by even the largest private enterprise.

It is therefore necessary to assess thorium-based fuel cycles in present-generation LWRs. The potential of large-scale deployment of such fuel cycles, even with relatively undramatic increases in the energy extracted per mined ton of uranium, may effect substantial savings in our uranium requirements. This not only could ease the pressure on uranium fuel costs but also provide more time for broad-scale deployment of FBRs.

A study performed by Combustion Engineering, Inc., evaluated various thorium-based fuel cycles in a standard (unmodified) C–E System-80 plant on a consistent basis (RP515-1). The aim was to provide a baseline for comparison of resource utilization with the conventional uranium cycle and with more advanced concepts. The economic motivation and the technical feasibility of employing thorium-based fuels in present PWRs were also determined.

The main conclusions reached in the study are:

- The largest savings in ore demand are realized with a thorium cycle that starts with fully enriched uranium.

- It is possible to realize about an 85% increase in the energy output per mined ton of uranium ore over that of the once-through uranium cycle and about a 22–23% increase over that of plutonium recycle.

- These increases in the efficiency of uranium utilization (which mean savings in uranium ore demand), however, occur later in plant life. The early years' uranium fuel and the separative work demands are higher compared with the once-through or the plutonium recycle mode of operation. Consequently, the thorium fuel cycles show greater 30-year levelized fuel-cycle costs.

- Thorium fuel cycles employing plutonium enrichment have a more limited long-term impact on uranium ore utilization because of the large fraction of the nuclear generating capacity that must be operated on the uranium fuel cycle to provide startup and make-up plutonium inventories.

- Thorium-based fuel cycles, however, represent a superior way of using existing plutonium stockpiles because approximately 20% more energy can be generated per kilogram of plutonium consumed in a thorium cycle than in the uranium cycle.

- Comparison of the characteristics of uranium and thorium-based cores indicates that thorium fueling is feasible and modifications to currently operating PWRs to accommodate plutonium recycle do not appear to be required. *Program Manager: B. R. Sehgal*

FUEL BUNDLE IRRADIATION STUDIES

The fuel bundle irradiation studies being conducted in cooperation with nuclear fuel vendors in operating power reactors are an integral part of EPRI's Light Water Reactor Fuel Performance Program (*1*). The gathering of detailed fuel rod performance data under prototypic conditions is essential input for the improvement of LWR fuel rod performance and reliability.

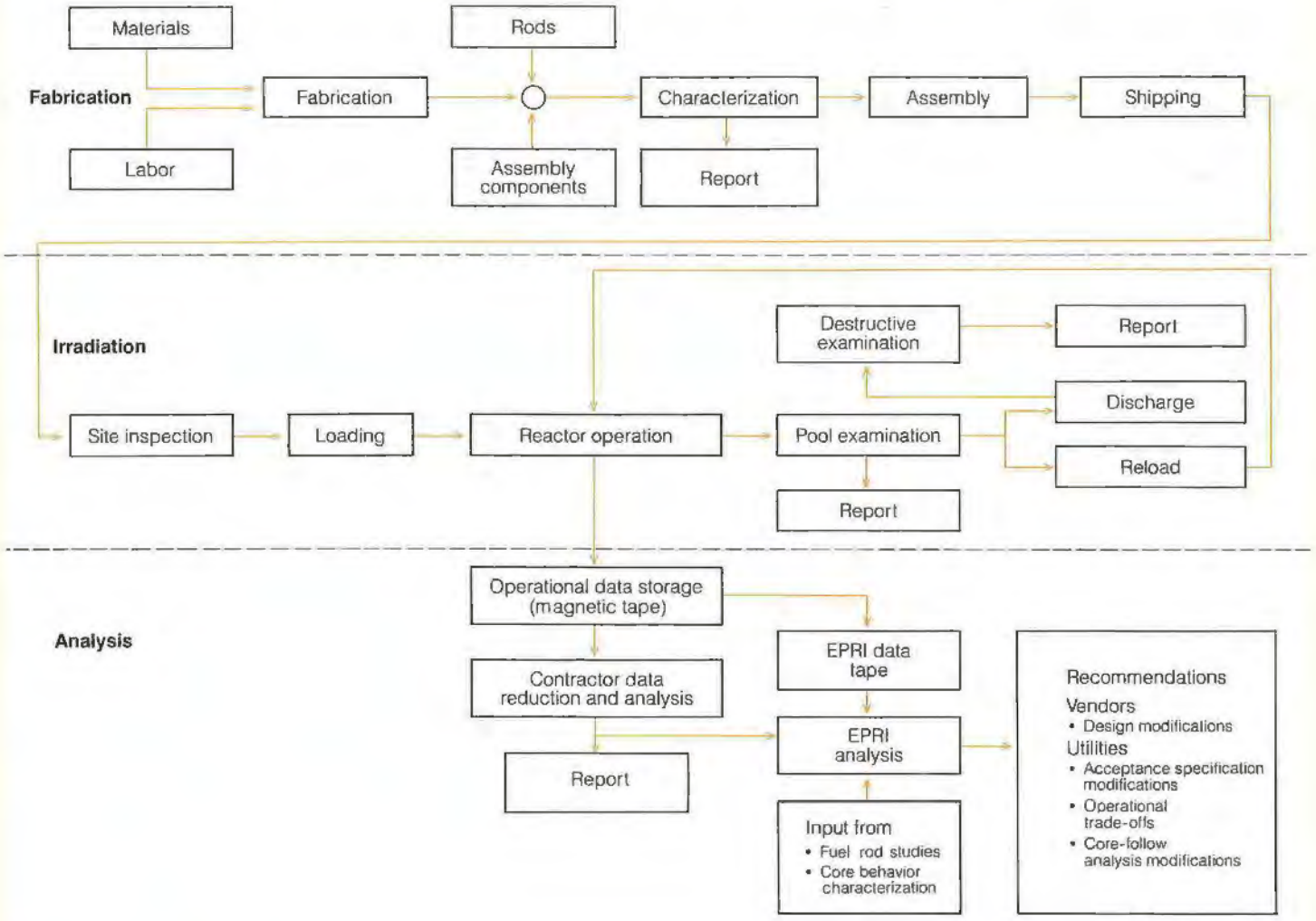
The major objectives of this project area are to:

- Provide benchmark data for the modeling of LWR fuel rod and fuel assembly performance

- Provide a separate-effects data link with laboratory and test reactor data

- Provide extensive high-quality data on fuel performance to help permit the identification of infrequently operative failure mechanisms

Figure 1 Flowchart of the Fuel Performance Program irradiation work shows the amount of detailed study in all three stages in the life history of a fuel rod: in the fabrication process before irradiation, during irradiation, and in analysis following irradiation.



▫ Demonstrate the reliability and safety of improved fuel designs or concepts

The fuel bundle projects are divided into standard product line bundle irradiations (where the emphasis is on obtaining statistics from large numbers of rods of recent design) and pilot bundle irradiations (in which fuel and cladding variables are introduced into special bundles for the purpose of studying separate effects under power reactor conditions). The latter projects include irradiation of plutonium recycle fuel, which has been described in an earlier issue of the EPRI JOURNAL (2). As illustrated in Figure 1, all the projects have in common the following distinct phases of work: (1) preirradiation characterization of the fuel rods and assemblies (i.e., detailed description of their metallurgical and dimensional features); (2) operational surveillance, which is conducted on the basis of reactor performance rather than at a set frequency; (3) extensive interim poolside examinations; (4) optional comprehensive postirradiation examination; and (5) correlation of observations with design and with operating history.

This is the first of a series of three reports describing the scope and status of the fuel surveillance projects. The first two will cover irradiation of standard product line fuel assemblies—this one, in BWRs; the next, in PWRs; the final report will describe pilot bundle irradiations.

Standard product line irradiations

The projects in this group will develop a data base that is keyed to current design but at the same time will include older fuel designs that still form a significant fraction of current core loadings. Thus, 14 × 14, 15 × 15, 16 × 16, and 17 × 17 PWR fuel designs; and 7 × 7 (Quad Cities-1), 8 × 8, 9 × 9, and 11 × 11 (Exxon) BWR designs are included in the bundle program (2). Fuel and cladding for the particular bundles designated for study came from normal production lots and did not receive special treatment. The difference between these rods and normal production rods is the high level of precharacterization and interim poolside inspection given them. In addition, destructive examination of selected rods is planned in most cases.

The scope of the currently contracted standard product line bundle irradiations is presented in tables 1 and 2; Table 1 details the tests and Table 2 shows the irradiation schedules. A status report on the BWR projects follows.

Peach Bottom irradiation project

The overall objective of the project is to obtain detailed irradiation performance data

Table 1 STANDARD PRODUCT LINE FUEL PERFORMANCE TESTS

	Preirradiation Data			*Cycle*	*Interim Nondestructive Examination**			
	Full Traceability	*Precharac-terization*	*Archive Materials*		*TV Visual*	*Length*	*Crud Sample*	*Profilom-etry*
RP611 Westinghouse Electric Corp.								
Surry-1	88 rods (removable rod assembly)	15 rods	Pellets 20 tubes 1 rod	1	4	4	Yes	4
				2	40	40	Yes	40
	and 528 standard rods	—	Pellets** Tubes Rods		100**	100**		20**
Surry-2	88 rods (removable rod assembly)	15 rods	Pellets 20 tubes 1 rod	1	40	40	Yes	40
				2	4	4	Yes	4
				3	40	40	Yes	40
	and 528 standard rods	—	—					
Zion-1	104 rods (removable rod assembly)	36 rods (104 radio-graphed)	Pellets 3 tubes 3 rods	1	4	4	Yes	4
				2	40	40	Yes	40
	and 39,000 standard rods	—	—					
RP586 Combustion Engineering, Inc.								
Arkansas-1	300 rods (removable rods in 6 bundles; 2 bundles removed each cycle)	300 rods	Yes, but quantities not yet determined	1, 2, 3	All 6 bundles	Bundles and peripheral rods	Yes	Target: 20 per batch
RP510 General Electric Co.								
Peach Bottom-2	248 rods (removable rods in 4 bundles)	60 rods	Yes, 4 rods (2 ft long) Pellets	1, 2, 3	15	15	Yes	15
				4	60	60	Yes	60

*Number of rods from removable rod assemblies, unless otherwise identified.
**Data apply to standard rods only.

					Hot Cell Postirradiation Examination*					
Leak Test	*Eddy Current Test*	*Ultrasonic Test*	*λ Scan*	*Grid Force*	*λ Scan*	*Length*	*Eddy Current Test*	*Fission Gas*	*Fuel Examination*	*Cladding Properties*
—	4	—	4	—	4	4	4	4	4	4
—	40 50**	—	—	12	6	6	6	6	6	6
—	40	—	20	12			Optional (extra cost)			
—	4	—	4	4						
—	40	—	20	12						
—	4	—	4	—			Optional (extra cost)			
—	40	—	20	12						
All 6 bundles	Target: 100	—	—	—			Optional (cost included in contract but scope not defined)			
							Optional (extra cost)			
All 4 bundles	15	15	—	NA						
All 4 bundles	60	60	—	NA						

Table 2

STANDARD PRODUCT LINE FUEL PERFORMANCE SCHEDULE

(by fuel irradiation cycle)

Plant	Design	1975	1976	1977	1978	1979	1980
Surry-1	17 × 17	Load — 1	1 — 2				
Surry-2	17 × 17	Load — 1	1 — 2	2 — 3			
Zion-1	15 × 15	Load — 1	1 — 2				
		June 1973					
Arkansas-1	16 × 16			Load — 1	1 — 2	2 — 3	
Peach Bottom-2	8 × 8		Load — 1	1 — 2	2 — 3	3 — 4	

from 60 well-characterized standard product line (8 × 8) fuel rods in four reload fuel bundles in Philadelphia Electric's Peach Bottom-2 reactor (RP510). The project includes study of the complete expected irradiation lifetime of the fuel bundles involved, covering a span of at least five years. It consists of three main tasks, namely, fuel rod preirradiation characterization, operation data acquisition and nuclear analysis, and interim site examination of selected rods and channels.

Detailed precharacterization of fuel, cladding, and fuel rod was completed in early 1976. Data included measurements of fuel pellet microstructure and density cladding tube texture, inner diameter and wall dimensions, fuel rod diameter, length, and bow. In addition, all 60 rods were eddy current tested and X-rayed. A precharacterization report is being issued.

At the spring 1976 outage, all four bundles under study were placed in a relatively high power region toward the center of the core. If at all possible, should a bundle be removed from the core for examination or for any other reason, it will be returned to its former core position for each irradiation cycle. If this is not possible, an alternative position will be found that provides the same physics and power environment. During reactor operation, sufficient core data are collected and stored on magnetic tape to permit a detailed rod axial-nodal power and burnup history to be computed for the four test bundles. In addition, all control rod movements adjacent to the four test bundles are monitored and stored on magnetic tape, and brief descriptions of all scrams, shutdowns, and abnormal transients (e.g., turbine trip, loss of feedwater heater) are also written.

The fuel bundles are completing their first irradiation cycle and interim site examination is in planning. The primary objective of this work will be to assess the effect of local irradiation duty cycle on fuel rod mechanical deformation, particularly the so-called pellet-cladding interaction (PCI) that can result in rod failure and the effects of coolant stresses and irradiation on channel performance. The intention is to leak-test and visually examine all four bundles, disassemble a designated baseline bundle, conduct a detailed examination of the 15 precharacterized rods, and inspect and measure the dimensions of all four channels.

The baseline bundle will be the only one examined after the first cycle of operation. During the subsequent two outages (i.e., following the second and third cycles), it is planned that additional bundles will be disassembled and precharacterized fuel rods will be inspected.

The actual number of additional bundles inspected will depend on the time window available in the refueling critical path time. After the fourth cycle of operation, when terminal exposures have been reached, all four of the surveillance bundles will be disassembled and all 60 precharacterized fuel rods will be examined.

Oyster Creek irradiation project

As part of a larger project to develop a corewide power shape monitoring system (PSMS), EPRI will also develop a data base on standard 8 × 8 reload fuel fabricated by Exxon Nuclear Co. Inc. (RP895). This project was described conceptually in an earlier issue of the EPRI JOURNAL (*3*). One task within this project includes fabrication, precharacterization, and irradiation of eight standard 8 × 8 fuel assemblies. Four reload bundles are currently under irradiation in Jersey Central Power and Light Co.'s Oyster Creek plant. Four more will be inserted in the same reactor in the spring 1978 outage. The work scope anticipated for the fuel surveillance is similar to that being undertaken by General Electric Co. (RP510). *Program Managers: J. T. A. Roberts and F. E. Gelhaus*

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2. Nuclear Power Division Report, *EPRI Journal,* Vol. 1, No. 3 (April 1976), p. 32.
3. Nuclear Power Division Report, *EPRI Journal,* Vol. 1, No. 9 (November 1976), p. 36.

Realities of Ecological Modeling

by Robert A. Goldstein

Ecological modeling as a tool for measuring environmental effects is gaining importance. Present capabilities and limitations of this mathematical approach are evaluated. ▫ An EPRI technical article

Robert A. Goldstein is a project manager for ecosystem analysis in the Environmental Assessment Department of EPRI's Energy Analysis and Environment Division.

Until recently, ecologists have devoted little effort to predicting the environmental changes caused by human-induced disturbances of natural ecosystems. Their studies have tended to be descriptive and have focused on the structure and dynamics of relatively undisturbed ecosystems. Thus, the accumulated knowledge and experience of ecologists and other environmental scientists are being severely strained in the attempt to meet societal demands to predict the ecological impact of energy technologies.

Fortunately, industry and government support of ecological assessment research has grown rapidly in the past decade. Experience is being accumulated and the ability to answer questions is improving significantly. Ecological scientists believe that mathematical models can play a major role in this improvement.

Goals of ecological modeling

Although some work in ecological modeling began in the 1920s, it is only in the past decade that modeling has taken an important role in ecological research. The application of modeling is valuable for increasing fundamental understanding of a system by synthesizing existing knowledge, analyzing hypotheses about a system's structure and dynamics, and identifying fundamental constraints on a system's functioning and the mechanisms to which a system's behavior is most sensitive. The formulation of a model at the initiation of a research program provides a valuable framework for organizing existing knowledge and integrating the efforts of individual investigators working on the program. It also leads to a review of current hypotheses concerning the system's functioning.

Analyses to identify fundamental constraints on a system's functioning and to determine factors to which a system's behavior is most sensitive can be applied both to properties inherent in the system (e.g., resistance of plant leaves to transpiration or natural mortality of fish larvae and eggs) and properties of the environment (e.g., precipitation patterns or elemental deposition through rainfall). While sensitivity analyses are often performed in connection with model development and application, constraint analyses are rare.

Within a given system, modeling can help identify processes where increased basic understanding is needed. For example, in formulating a model for studying effects of acidic deposition on forest growth and development, it would become apparent that current understanding of elemental movement from soils into roots is inadequate. Application of models leads to identification of information gaps in the available data that need to be filled in order to evaluate important parameters.

Over the next decade, modeling should become an important means of addressing questions related to environmental assessment of disturbances and to management strategies applied to ecosystems. Mechanistically based models have the greatest potential in this area. In a mechanistic model, each parameter has some physical, chemical, or biological interpretation and can be estimated independently of most of the other parameters. Abiotic factors (e.g., temperature, moisture, solar radiation) that are important in controlling ecological processes need to be explicitly included in the models that are applied to environmental assessment questions, since in most situations it will be an alteration of the abiotic environment that will have the most pronounced and long-lasting impact on the system.

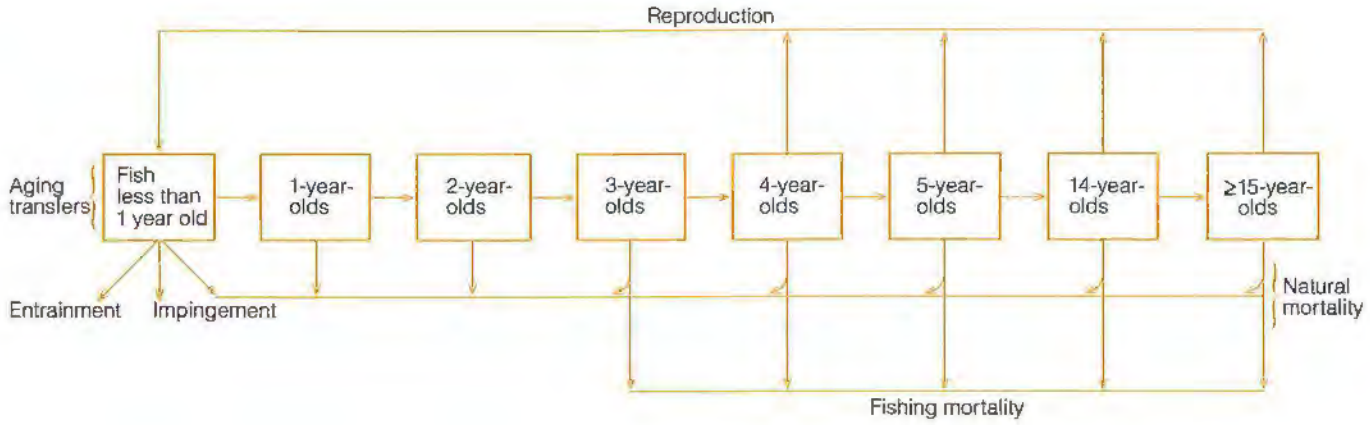
Ecological models are frequently divided into three classes: population, process, and ecosystem. These classes are not precisely defined, so there is some ambiguity as to which term best describes a particular model. In fact, most working models contain elements of more than one class.

Population models

Population models deal with the population dynamics of animal and plant species. These models incorporate basic population processes, such as natality, natural mortality, predation, competition, and migration. The dependent variables are population densities, which are measured in terms of density of individuals or biomass (total weight of a group of organisms). Historically, population models rarely have explicitly incorporated environmental factors, such as temperature, humidity, and solar radiation. The models were studied by analytic and graphic techniques and, therefore, had to be kept simple. Now, with the widespread use of computers, the models have become more complex and do include environmental parameters. So far, most effort has been directed to animal populations, but the models are also applicable to plant populations.

In assessment of the impacts of once-through cooling systems, population models have been applied to estimate effects of impingement of fish on intake screens and entrainment of fish larvae and eggs by cooling waters flowing through power plants. Probably the most widely known application of this type involves the assessment of the impact of power plants along New York

Figure 1 A schematic of an ecological population model designed to estimate the impact that cooling systems of power plants along New York's Hudson River have on the river's striped bass population. Population processes indicated are aging, reproduction, and mortality from natural causes, fishing, entrainment, and impingement (*1*, adapted).



State's Hudson River on the adult striped bass population (*1, 2*). A schematic of a striped bass population model is illustrated in Figure 1. Various mathematical formulations are used to represent the transfers shown. Application of the model requires estimation of the values of the parameters that define the mathematical formulations. Estimates would be based, wherever possible, on experimental data. Such a model can fail to accurately depict the true population dynamics if either the mathematical formulations or the parameter estimates are incorrect.

Concern exists about the striped bass because of its importance as a commercial and sport fish. Striped bass is an anadromous species, that is, it spends most of its adult life at sea but migrates into freshwater portions of estuaries, such as the lower Hudson River, to spawn. As a result, striped bass eggs, larvae, and juveniles become vulnerable to entrainment and impingement by Hudson River power plants.

The crucial assessment question is, How does power-plant-induced mortality of striped bass eggs, larvae, and juveniles ultimately affect the adult population size and the sport and commercial fisheries? The magnitude of the cooling system impact on the adult population is unknown and is not easy to assess among all the other factors that variably affect populations each year. Typically, there are few, if any, baseline data taken over several striped bass generations to establish the relationship of population size to changing natural factors, such as river volume and flow, food availability, weather, predation, disease, and parasitism. Similarly, data relating striped bass population size to sport- and commercial-fishing pressures are scarce. It should be noted that it is a complex matter just to estimate the size of the total striped bass population, and any such estimate probably includes at least a 50% uncertainty. Assessing the magnitude of the power plant impact among other human-induced effects and the dramatically changing natural environment is no easy task.

A second example of the application of population modeling to assessment of the impact of egg and larvae entrainment involves the winter flounder population of Connecticut's Niantic River. A population model has been used to estimate the impact of a nuclear power station at Millstone, Connecticut, on the Niantic River's winter flounder population (*3*). Conservative assumptions were made in applying the model so that the estimate of impact would represent an upper bound on the potential change in population size. The result was a potential 6% decrease in total population size after 35 years of power plant operation. As stated before, such a small decrease would be virtually impossible to verify experimentally, especially since it would take place over a time span of 35 years.

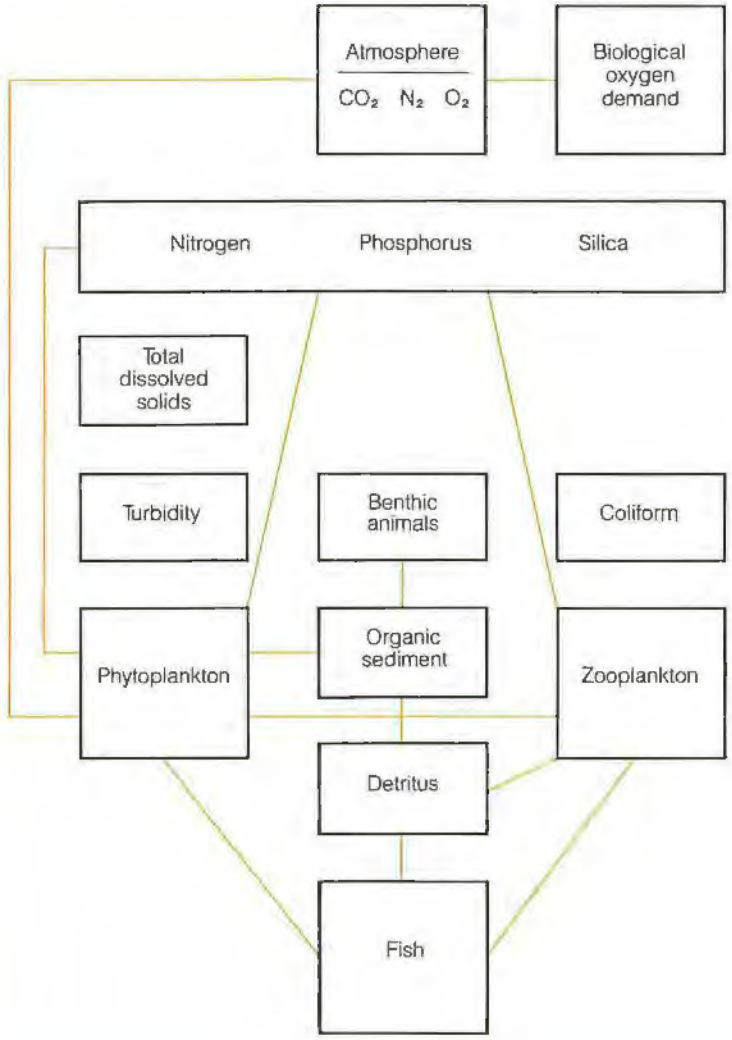
Process and ecosystem models

Process models focus on the dynamics of major physioecological processes, such as photosynthesis and thermoregulation. These models explicitly incorporate basic physical, chemical, and physiological mechanisms that govern the processes and also include such environmental factors as temperature, humidity, and solar radiation, which influence these mechanisms. Dependent variables include energy, biomass, water, and nutrients being accumulated and transferred. Process models are most frequently applied to the study of vegetation.

The third type of model, the ecosystem model, focuses on the integrated dynamics of the entire community. It describes the flow of energy, biomass, nutrients, and water through the ecosystem. Because of the ecosystem model's scope, it does not contain the detailed chemistry, physics, and physiology of a process model. The ecosystem model includes elements of both the process and population models but tends to have coarser temporal and spatial resolution than a process model.

As ecological models have developed,

Figure 2 Major components of an ecosystem model developed to assess the ecological impact on Lake Ontario, New York, of the cooling systems of power plants sited on the lake. Behavior of a cooling system can be simulated by forcing functions coupled to the model, which simulates the hydro, chemical, and biological dynamics of the lake (*4*, adapted).



the population and process models have been applied to problems of ecological assessment more extensively than has the ecosystem model. An ecosystem model (Figure 2) has been developed for Lake Ontario to assess the ecological impact of thermal power plant cooling systems (*4*). The modal simulates the hydro, chemical, and biological dynamics of the lake. The behavior of the cooling system can be simulated by forcing functions coupled to the lake ecosystem model. For instance, a sink for fish larvae and eggs can be used to simulate entrainment at an intake location. Since most of the chemical and biological reactions in the model are explicit functions of temperature, the effects of heated discharge on the total ecosystem can be simulated.

Refinements needed

A mathematical model of a system attempts to depict essential features of the system, relevant to specific objectives. If the attempt is successful, the model can be considered realistic. However, the fact that a given model is realistic does not necessarily mean that it may be applied to an arbitrarily chosen real system in such a manner that the behavior of the model matches, according to some set of independent criteria, the behavior of the real system. For instance, it is straightforward to develop a mathematical life cycle model of a striped bass population that incorporates the multitude of factors that affect survivability and growth of the different life stages. On the other hand, it is an enormously complicated, expensive, and lengthy procedure to quantify all the factors for a given ecosystem, such as the Hudson River.

Through an extensive search of the literature, data for similar species and locations can be acquired which, along with educated guesses and Hudson River striped bass data, can be used to quantify the model. We would then have a working model of a hypothetical, but realistic, striped bass population. The simulated response of the hypothetical population to an environmental disturbance would be plausible (realistic), but the response of the actual Hudson River population would be still unknown. Minor changes in a few of the model's parameters could radically alter the simulated impact. The dilemma is that the range of what is plausible greatly exceeds the range of accuracy in simulation that is required for impact assessment. (This hypothetical situation is presented simply to illustrate the previous point about realism and ecological models. It should not be considered a critique of any of the models cited in this discussion.)

Factors limiting models

Over the last decade, ecological scientists have made considerable progress in developing realistic mathematical models of ecological phenomena and systems. However, several major factors exist that limit the ability of these models to predict what will be the effects of a disturbance of a specific real system. These factors identify research topics that mathematical and theoretical ecologists should be considering and include: lack of fundamental unifying theories; sparse data sets; biological variability; spatial heterogeneity; interactions of processes operating at significantly different temporal and spatial scales; and nonlinearity.

Difficulties associated with ecological applications of mathematical models are not necessarily unique to ecology nor do they negate the value of such models to meet the ecological modeling goals already discussed. Nonetheless, these current difficulties should not be ignored.

Ecology as a science is in its early stages of development. As such, ecology has not yet formulated fundamental unifying theories that can be used to deduce quantitative ecological behavior. Ecology comprises a number of loosely defined principles concerning concepts such as succession, competition, diversity, and stability. However, these principles tend to be qualitative and there is con-

siderable uncertainty about their validity.

It is difficult to validate a generic model for a given ecological phenomenon (e.g., phytoplankton primary production) or system (e.g., forest growth and development) because of a lack of complete data sets in the ecological literature. Many data sets exist for a given phenomenon or system, but few, if any, contain measurements of all the extrinsic and intrinsic factors that are important in controlling the dynamics. It is also difficult to apply an ecological model to a specific situation (be it a location, community, or species) because the data will probably not exist to quantify all the model's parameters for that specific situation. It should be noted that long periods are usually required to collect the data needed to estimate the parameters for or validate an ecological model.

Biological variability is another difficulty. It is this variability that makes ecosystems so much more difficult to model than physical systems. All protons placed in identical environments appear to respond identically. However, all striped bass placed in identical environments will not respond identically. Differences in biological responses between individuals of the same species or representative samples of the same community can be based on genetic differences, environmental preconditioning differences, or combinations of the two. Biological variability poses special problems for ecologists attempting to develop and apply deterministic models.

Spatial heterogeneity in the environment conditions biota to respond differently to identical situations and hence produces a spatially dependent biotic response surface. Therefore, considerations of spatial heterogeneity and biological variability are connected in some aspects. Spatial heterogeneity can be an important factor influencing system dynamics and stability. Spatial heterogeneity presents a conceptual difficulty to ecologists attempting to develop and apply point models, that is, models where spatial dependencies have been removed by integrating the spatially dependent factors over all of space. The problem is how best to integrate or average out the spatial dependencies. Explicit treatment of spatial heterogeneity also presents difficulties, since it drastically increases the complexity of the model.

The potential importance of spatial distribution is clearly brought forth in a study that critically compares the capabilities of several mathematical models to predict entrainment of Hudson River striped bass eggs and larvae (*5*). Differences in assumptions regarding the spatial distribution of eggs and larvae can produce dramatically different estimates of percentage entrained. Models that ignore or do not correctly treat the nonuniform spatial distribution of eggs and larvae will produce major misconceptions regarding entrainment vulnerability.

Wide range of factors

In conducting ecological research, we are confronted with a large array of interacting phenomena whose fundamental dynamics conceptually lie within an extremely broad range of temporal and spatial scales of resolution. The phenomena range from the biochemical to the physiological, to the ecological, to the landscape, and finally to the global. There is a corresponding spatial scale that goes from the cell, to the individual organism, to the community, to the watershed, to the geographical region. The time scale ranges from seconds to centuries. It is of questionable value to attempt to construct a single model that encompasses the entire hierarchy of processes or to devote all our energies to a single level of the hierarchy.

The best procedure is to view the system from several levels of the hierarchy simultaneously by developing and applying a suite of models, each appropriate to a given spatial-temporal level of resolution. Such an approach has been employed by several groups modeling the impact of power plants on the Hudson River striped bass fishery. Separate models (*6*) have been developed to examine the young-of-the-year (zero age class) striped bass dynamics, since this age class is most vulnerable to entrainment and impingement, and the vulnerability and natural mortality of this age class are in a constant state of flux. The young-of-the-year models have finer spatial-temporal resolution than do the models developed to simulate the total population (Figure 1).

The final factor involves the inherent nonlinearity of ecological phenomena and systems. It is common to find nonlinear interactions dominating the dynamics of ecological phenomena and systems. The classical example is the predator-prey interaction. Both threshold and saturation reactions occur commonly in ecological systems. Nonlinear models, in contrast to linear models, pose special problems relating to mathematical analysis. The capability to derive analytic, in addition to numerical, solutions to a mathematical model is highly valuable. Analytic procedures give greater insight into the functioning of the system than do numerical procedures. Analytic procedures are valuable tools for checking the model for logical or conceptual inconsistencies. Although nonlinear interactions make the mathematical analysis of a model more complex, they frequently increase the stability of a system and hence simplify the system's dynamic response to disturbance.

Future trend

The mathematical modeling of ecological phenomena and systems is a discipline that abounds in both potentialities and problems. Considerable time and effort will be required to solve the problems and realize the potentialities. This past decade has witnessed major progress in integrating mathematical modeling into ecological research and in developing general ecological models. During the next decade, this trend is expected to continue and expand with widespread application of models to help solve the problems of environmental assessment.

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New Technical Reports

ELECTRICAL SYSTEMS

Some Theoretical Considerations Affecting the Design of Lapped Plastic Insulation for Superconducting Power Transmission Cables

EL-269 Final Report (RP7844-1)

There is great interest in the possibility of replacing with a polymeric plastic the paper tape traditionally used to insulate power transmission cables. As cable voltages approach the EHV region, it is important to reduce dielectric heating. Flexible superconducting cables designed for ac transmission must also use polymers. The problem of lapping and bending the cable at room temperature is shared with the EHV development. Additional problems arise when the cable is impregnated with supercritical helium.

This study investigated both areas: taping plastic with conventional winding machines and the electrical performance of helium-impregnated lapped tapes. The taping problem was not solved, but possible lines of material development were suggested. The dielectric tests showed that the helium conditions in the butt-spaces dominated the achievement of highest-possible corona inception stress. *Brookhaven National Laboratory*

Development of Current-limiting Conductor

EL-286 Final Report (RP324-1)

This report describes the theory of the current-limiting conductor (CLC)—in principle a linearly extended solenoid. Its inductance increases as the air gap between the armature and the core is reduced by magnetic forces resulting from the short-circuit current. The report presents design formulas for the CLC concept and an analysis of the nonlinear interaction of the electric circuit, magnetic circuit, and mechanical system.

A peculiar beat pattern of the limited current was observed in this study and was mitigated by increasing the losses of the CLC. Analysis suggested switching a resistor into the circuit. The term *CLC with resistor* was coined and commutation of current to the resistor explored. A cost analysis indicated that inclusion of the resistor may reduce the cost of the CLC by 90%. Fractional CLC devices with and without resistor were designed. The latter was tested with prospective short-circuit currents up to 40,000 amps. *Phoenix Electric Corp.*

138-kV Splice for Extruded Dielectric Cables

EL-354 Final Report (RP7815), ERDA E(49-18)–1559

This publication reports on the development of a straight splice for 138-kV extruded dielectric cable. The splice makes use of premolded, interference-fit, elastomeric components that can be factory-tested before installation. It can be assembled (including cable preparation) by two men in about five hours. *Amerace Corp.*

An Investigation and Status Report on Concentric Neutral Corrosion of URD Extruded Cable

EL-362 Final Report (RP747-1)

The use of cables with extrudad insulation and concentric neutral wires has been widely accepted for underground distribution in recent years and is likely to continue. However, recent reports of corrosion of the neutral wires have produced concern since their integrity provides a low impedance for both load and short-circuit currents and maintains acceptable voltage levels during short circuit.

This report is a compilation of the information obtained from a literature search (Phase I, Appendix A) and a field investigation (Phasa II, Appendix B). Results obtained in corrosion surveys of URD cables (Appendix C) are also included. The project concentrated on ascertaining present opinions about the cause or causes of concentric neutral corrosion and present industry practice in corrosion mitigation. *Harco Corp.*

Underground Cable Fault Location

EL-363 Final Report (RP481-1)

This handbook is designed to serve as a reference document to guide utility operations personnel in the selection and use of fault location equipment for underground power cables. The final report for this project, EPRI TD-153, presents the technical results of the study. *BDM Corp.*

Controlling Biological Deterioration of Wood With Volatile Chemicals

EL-366 Interim Report (RP212-1)

Agricultural fumigants poured into holes from which they diffused through the wood as gases proved to be the first successful method for controlling internal decay of poles. Chloropicrin and Vorlex eliminated decay fungi from and persisted in Douglas fir poles for seven years. Vapam was not quite as effective.

Biological procedures were developed to obtain fungi from Douglas fir poles to distinguish between decay and nondecay fungi and to detect preservative or fumigant depletion so that supplemental treatments could be applied before significant reductions in pole strength occurred.

Eight decay and 29 nondecay fungi were obtained from 3111 Douglas fir poles in western Oregon. Decay fungi rarely were obtained whereas nondecay fungi frequently were obtained from cedar and southern pine poles. An extension of this work will concentrate on these species. *Forest Research Laboratory, Oregon State University*

Long-Term Power System Dynamics

EL-367 Final Report (RP764-1)

This report contains results of Phase II research on long-term system dynamics. Phase I, completed in 1974, undertook a survey of major power system disturbances in the U.S. and Europe that were caused by an imbalance between generation and load. This phenomenon, defined as long-term power system dynamics, is one factor in the propagation of major, widespread blackouts. Such disturbances have not been analyzed properly in the past because the industry lacked an accurate computer model to portray the long-term system behavior.

The purpose of RP907-1 was to develop a prototype computer model to be used for study of efficient corrective measures to lessen the impact of such disturbances. In this effort, the systems analyzed have been expanded in size to include models of such critical components as the BWR and the combustion turbine. *General Electric Co.*

Research and Development on DC Circuit Breakers

EL-379 Final Report (RP91)

This report describes the development and testing of a laboratory prototype of an HVDC circuit breaker. Testing was conducted on the Pacific NW-SW DC Intertie rearranged to represent a three-terminal system. The fundamental difference from previous concepts in breaker configuration was the partitioning of the breaker functions of carrying the continuous current, interrupting fault or load currents, and absorbing energy into separate devices: (1) an ultra-fast, in-line mechanical switch capable of full opening (1 in) in 1.6 milliseconds, (2) a unique electronic interrupter, and (3) a nonlinear energy-absorbing resistor. The appendix referred to in this report is a separate document and is available on request from EPRI. *Hughes Research Laboratories*

ENERGY ANALYSIS AND ENVIRONMENT

A Comparative State-of-the-Art Assessment of Gas Supply Modeling

EA-201 Final Report (RP436-1)

This report presents a state-of-the-art comparison of twelve major gas supply modeling efforts as categorized into three general classifications: structural models of resource economics, pure econometric models, and resource base–geologic models. In addition to the model-by-model assessments presented in Part III of the report, parts I and II provide a detailed discussion of the natural gas supply sector to give the reader some background and perspective into the importance of natural gas in the domestic energy economy and the pattern of evolution that has significantly influenced the industry's current composition and condition. In particular, Part III defines the elements of the gas supply process as well as the chronology of gas supply modeling efforts and the characteristics that distinguish them. Part IV summarizes and reinforces the observations presented for each model individually in Part III and presents a concise reiteration of model strengths and weaknesses, alternative projections and forecasts, and the implications of these methodologies for future research and policy analysis. Part V is concerned with the state of the art and recommends the next steps to be taken in future research efforts in this area. *Mathematica, Inc.*

FOSSIL FUEL AND ADVANCED SYSTEMS

Advanced Thermal Energy Storage Systems

EM-256-54 Interim Summary Report (RP788-1)

In February 1976 an EPRI–ERDA coordinated program was initiated to examine in detail the technical feasibility of high-temperature thermal energy storage. The two advanced systems studied are a phase change energy storage system with inorganic salts and a reversible thermochemical reaction energy storage system. A third system, a sensible heat pebble bed energy storage system, was investigated as a near-term benchmark. *Boeing Engineering and Construction*

Synthetic Electric Utility Systems for Evaluating Advanced Technologies

EM-285 Final Report (TPS75-615)

This report presents the results of the first step in the development of a systematic method of evaluating new alternative technologies on the U.S. power system. Six generation and transmission scenarios, a "plug-in" distribution system, and data typical for utility system components have been developed. These systems and data are broadly representative of utility system characteristics as projected for the mid-1980s. *Power Technologies Inc.*

Application of Advanced Materials and Fabrication Technology to Letdown Valves for Coal Liquefaction Systems

AF-305 Final Report (RP458-1)

This is the final summary report of a program that covered a period of performance from May 1, 1975 through July 31, 1976. The program included a survey of liquefaction processes and related wear problems, with particular emphasis on letdown valves, and an experimental program of materials fabrication and wear-test evaluation.

In the survey early experimental coal liquefaction processing endeavors made in both Germany and the U.S. were reviewed. Additionally, five major process development efforts ongoing in the U.S. were covered. The literature shows only a limited understanding of the mechanisms involved in wear processes in liquid systems and at elevated temperatures. No experimental work on coal-derived abrasive oil slurries was found.

The report also describes the experimental wear-test system that employs an ash-containing coal-derived slurry as the eroding medium. It was found that the wear produced in cemented carbides was similar to that observed in actual worn valve-trim components. The results of metallographic examinations of the base materials and of scanning electron micrographic examination of the eroded surfaces are presented and discussed. *Battelle, Pacific Northwest Laboratories*

Summary Evaluation of Atmospheric Pressure Fluidized-Bed Combustion Applied to Electric Utility Large Steam Generators

FP-308-SY Summary Report (RP412-1)

The combustion of pulverized coal in suspension is the most widely used method employed in coal-fired electric utility steam generators. This method, developed over 40 years ago, has been improved over the years but the basic principle remains the same. With the advent of more stringent air pollution control legislation, the development of advanced combustion technologies may be required.

An atmospheric pressure fluidized-bed combustor has been proposed as an alternative to the conventional pulverized-coal boiler equipped with its tailend scrubbing system. The major potential advantages of fluidized-bed combustion are the removal of SO_2 within the fluidized bed using limestone and the lowering of NO_x due to lower combustion temperatures.

The purpose of this project was to collect available data, to establish, where feasible, criteria for the design of a fluidized-bed combustor steam generating system, and in addition, to identify those areas where additional activity is required. *Alliance Research Center*

Proceedings of an EPRI Workshop on Technologies for Conservation and Efficient Utilization of Electric Energy

EM-313-SR Special Report (TSA 76-58)

This workshop examined the R&D needs for efficient energy use as they affect the electric utility industry. Both the physical basis of efficient energy use (technology) and the institutional factors (regulations and consumer end use) were considered. The workshop defined these broad approaches to energy conservation, suggested EPRI's role for each of them, and established a list of R&D priorities in the residential, commercial, industrial, and transportation sectors. *Applied Nucleonics Co., Inc.*

Stack Gas Reheat for Wet Flue Gas Desulfurization Systems

FP-361 Final Report (RP209-2)

A major problem in operating wet flue gas desulfurization systems is the need for stack gas reheat. Reheat is required to avoid downstream condensation and corrosion, to avoid a visible plume, and to enhance plume rise and dispersion of residual pollutants. The minimum degree of reheat required depends on the objective, whereas the minimum heat requirement depends on the degree of reheat, the method, and the quantity of mist carryover from the scrubber. In general, avoidance of downstream condensation requires the smallest degree of reheat. Methods currently in use include in-line reheat, indirect hot air reheat, and direct combustion reheat. Bypass, exit gas recirculation, and waste heat recovery are not currently used but have also been considered and experimentally tested in this study. *Battelle, Pacific Northwest Laboratories*

Proceedings of Semiannual EPRI Solar Program Review Meeting and Workshop

ER-371-SR Special Report

EPRI has funded an extensive program in solar energy R&D in order to define and develop those solar energy systems that incur the lowest cost when integrated with utility networks and to define the impact of solar energy system interactions with these networks.

During the week of March 8–12, 1976, EPRI sponsored the first semiannual program review meeting and workshop in San Diego, California (EPRI ER-283-24, Vols. I and II). The second meeting was held in Falmouth, Massachusetts, October 6–8, 1976; its proceedings constitute this report.

The first part is concerned primarily with solar heating and cooling and the second part with solar electric power and environmental impact of various solar plants. *Atlas Corp.*

Design and Cost Study for State-of-the-Art Lead-Acid Load-leveling and Peaking Batteries

EM-375 Final Report (RP419-1)

This design and cost study has applied state-of-the-art tubular positive lead-acid battery technology to estimate the selling prices for one 25,000-cycle, 10-MW, 100-MWh load-leveling battery and two 2000-cycle, 20-MW peaking batteries delivering between 60 and 100 MWh. Battery accessories to meet EPRI performance and life requirements are described and priced. Prices include transportation and installation and are reduced by salvage-reuse credits for the second battery purchased. Amortized in the price is a battery-manufacturing plant investment of $14.4 million for a three-shift operation producing 1000 MWh/yr.

NUCLEAR POWER

Prediction of Thermal-Hydraulic Performance of Gas-cooled Fast Breeder Reactors

NP-156 Final Report (RP400-1)

The gas-cooled fast breeder reactor (GCFBR) is viewed as a potential backup for the LMFBR. A modest subprogram in GCFBR has been under way for the past two years in the Developing Applications and Technology Program. The thrust of this subprogram was to initiate a continuing appraisal of critical technical details concerning the GCFBR.

This report describes an examination of thermal-hydraulic performance of gas-cooled fast breeder reactors. Existing GCFBR designs are briefly described with emphasis on the core-cooling and associated systems. Factors affecting the convective heat transfer and pressure drop in the core are examined, particularly the effects of surface roughness on the enhancement of heat transfer, the effects of the variation of the coolant's thermophysical properties with temperature and composition, and the influence of cross flow and cross mixing. The characteristics of other components of the cooling system, the helium circulator, and the steam generator are examined with particular emphasis on off-normal operation. Existing computer codes for the prediction of both normal and abnormal operations are described and compared. Two new codes developed under this project are described, and some preliminary results of their application to GCFBR thermal-hydraulic performance are given. These codes are: (1) AVFLO, a relatively simple and inexpensive program for the evaluation of reactor core axial temperature distribution at steady-state conditions; and (2) RETSAC, which is of the SABRE/COBRA IV category but appears to enable detailed analysis of reactor transient with little or no iteration. Problem areas pertinent to cooling-system performance and safety are summarized, and recommendations are made for additional research to assume economical design and safe operation. *Rand Corp.*

Evaluation of Societal Risks Due to Reactor Protection System Failure, Vol. 4: The Probability of Exceeding 10CFR100 Guidelines From ATWS Events in LWRs

NP-265 Key Phase Report (RP767)

This is the fourth and final volume of Part II in a series of studies examining the problem of anticipated transients without scram (ATWS). This volume considers the probability of an ATWS releasing sufficient radiation to violate the radiation limits set by 10CFR100. Our calculations show that the probability of such a violation is less than 3×10^{-7}/yr (3 chances in 10 million). Since WASH-1270 stated that a desirable probability would be on the order of 10^{-7}/yr, it would appear that such a limit has already been met. *Science Applications, Inc.*

1/20-Scale-Model Pump Test Program: Preliminary Test Plan

NP-292 Key Phase Report (RP347)

This report describes the pump two-phase performance test program for Task A of the Light Water Reactor Safety Research Program. The report describes the test program and the logic behind its development and discusses the instrumentation requirements and approach to be used for two-phase measurements.

The test program has been structured to emphasize the need for the study and definition of flow regime structure at the pump inlet, as well as steady-state and transient measurements of model pump two-phase performance. A study will be made of oscillation phenomena within the pump and/or in the associated piping loop system. A portion of the program is aimed at providing information on the two-phase measurements made by drag disc and turbine meter instrumentation. An overall experimental program schedule to meet the program objectives is outlined. *Creare Inc.*

The Cladding Flaw Growth Index: A Method for Corewide Fuel Rod Reliability Prediction

NP-324-SR Special Report

This report describes an analytic logic system that can be used to define the state of a reactor core with respect to the probability of the loss of fuel rod cladding hermeticity. The cladding flaw growth index (CFGI) logic for computing the probability of cladding failure as a function of axial location along each fuel rod depends on the calculated linear heat generation rate (LHGR) variation of this specified length of the fuel rod as a function of irradiation. It also assumes that the probability of failure depends on both a current power maneuver and all previous power change events (i.e., it assumes that failure can result from a cumulative process). This logic system can be used to aid in the location (detection) of failed fuel bundles and as part of a computation system, to evaluate and anticipate the effects of power change maneuvering (duty cycle) on fuel rod reliability.

Review of In-Core Power Distribution Measurements—Technical Status and Problems

NP-337 Final Report SOA 75-318

This report reviews the technical status and problems associated with on-line measurement of core power distributions in nuclear reactors. The need for and significance of the various measured and inferred quantities relating to power distribution are defined. Instrumentation and data acquisition systems are supplied by the four domestic LWR vendors. The techniques employed with each of these systems to process the measurements on-line and to infer the different power distribution parameters are also documented. Sources of uncertainty in the inferred power distribution and problems with the measurement systems are identified, and the impact that they may have on plant operations is enumerated. Examples are cited where plant operation has been restricted for these reasons. The report concludes with a summary of areas where additional research and development might be beneficial. *Nuclear Associations International Corp.*

ZORO 1—A Finite Difference Computer Model for Zircaloy-4 Oxidation in Steam

NP-347 Topical Report (RP249-2)

One objective of the EPRI Light Water Reactor Fuel Performance Program is to develop an accurate description of reactor material responses to hypothetical accident conditions, providing an improved basis for LOCA calculations. One aspect under investigation by EPRI and NRC is oxidation behavior of Zircaloy under high-temperature conditions. Modeling of Zircaloy oxidation under arbitrary transient conditions has led to the development of the TRANS 1 and ZORO 1 computer codes.

ZORO 1 characterizes the oxidation behavior of Zircaloy-4 in steam using a finite difference analytic technique for oxygen diffusion into the cladding. The purpose of this report is to present the ZORO 1 computer code in a convenient form for use. Examples of prediction capability for a variety of oxidation events are demonstrated to explain various input and output options available. The modeling used is capable of handling any two- or three-phase system with one element diffusing under transient temperature-time conditions. The fundamental variables of oxygen diffusion and interface oxygen concentrations associated with phase equilibrium are required, along with the desired temperature transient. Output includes oxide and ξ thicknesses, an oxygen concentration gradient in all phases present, oxygen absorbed in each phase, total oxygen absorbed, and a prediction of α incursion formation based on oxygen saturation of the β phase. *Worcester Polytechnic Institute*

The Application of Two-Phase Flow Modeling

NP-349 Final Report (RP599)

This report describes research conducted to further the development and application of the theory of multiphase flow in those areas pertinent to LWR safety. A careful review made of a deductive approach to modeling was documented in an earlier report (EPRI NP-197). In this report, the principles of this rational approach are applied to the boiling of superheated water in a pipe: Standard Problem 1. It is shown that a careful consideration of the time scales of the underlying processes reduces the abstract formulation to a simple description.

An evaluation of currently available computational methods for calculating multiphase flow resulted in the conclusion that these techniques do not meaningfully address engineering needs, both because the description of physical processes is inadequate and because the computation artifices employed are unproven and at times inconsistent. *Jaycor*

Assessment of Thorium Fuel Cycles in PWRs

NP-359 Final Report (RP515-1)

An alternative fuel resource for nuclear power is thorium, which on irradiation in the reactor converts to the highly efficient fuel resource ^{233}U. Utilization of thorium has the potential of increasing the amount of energy extracted per mined ton of our uranium fuel resource. This potential of thorium can only be realized, however, if the reprocessing of thorium-based fuel is in place.

The study reported has evaluated various thorium-based fuel cycles in Combustion Engineering Standard System 80™, a large capacity PWR plant. The technical and economic feasibility of employing such cycles is also evaluated. The results will serve as a baseline for comparison with the present mode of utilization of uranium as well as with more advanced fuel cycles. *Combustion Engineering, Inc.*

Study of the Developmental Status and Operational Features of Heavy Water Reactors

NP-365 Final Report (517-1)

The objective of this project was to provide a focused study of the development status and operating features of heavy water reactors, including the potential feasibility, applicability, and minimum design changes to apply the CANDU system in the U.S. The work was structured to proceed in three phases: I, an overview of the reactor system and identification of key technology issues; II, in-depth evaluation of key technology from Phase I; and III, program report. Only phases I and III were completed. Additional expenditure on further evaluation of key technology issues would not significantly reduce the uncertainties identified in the present report.

The reader of this report is specifically cautioned not to assume too great a potential for the advanced CANDU reactor as a breeder or near-breeder using the self-sustaining equilibrium thorium fuel cycle, without giving careful consideration to design and licensing criteria differences and technological uncertainties. The important question for policymakers is the number of alternative technologies a nation can afford to carry to the multiple-unit commitment phase. Viewed in this context, the goals of the U.S. and Canadian programs may be consistent while at the same time pursuing different breeder reactor approaches. *General Electric Co.*

Planning Support Document for the EPRI LWR Fuel Performance Program

NP-370-SR Special Report

This report describes the various projects comprising the EPRI LWR Fuel Performance Program. The overall goal of this program is to develop a comprehensive fuel performance data base with verified predictive models and codes that can be used to improve fuel rod reliability and hence increase plant availability.

The LWR Fuel Performance Program integrates 20 active research projects ranging in scope from laboratory tests of Zircaloy-cladding tube

behavior under hypothetical LOCA conditions to large-scale testing of prototypic fuel assemblies in operating power reactors. The program has been assembled over the last two years; a first program planning document was issued as EPRI SR-25 in December 1975. This revision includes a status report on projects described in SR-25 and details new projects under contract since December 1975 or currently in the planning stages.

An Investigation of Mechanical Properties and Chemistry Within a Thick NmMoNi Submerged Arc Weldment

NP-373 Topical Report (RP232-3-0)

Mechanical properties of thick sections of pressure vessel steel vary with location through the thickness of the section as a result of cooling rate during heat treatment and metal working during rolling or forging. The ASME Boiler and Pressure Vessel Code requires that samples for mechanical property measurements of plates, forgings, and weldments be taken from the ¼ thickness plane of the product. This ensures for plate and forging that the sample does not have higher than average properties due to surface cooling and working effects. However, the reasons for properly variation in thick plate and forging probably do not hold for welded material because fabrication procedures dictate that the material is built up layer by layer.

This study was conducted to determine the variations in mechanical properties and chemical analysis in a thick submerged arc weldment and thus evaluate present ASME requirements. Mechanical properties and chemical analysis of a 12-in thick MnMoNi automatic submerged arc weldment were characterized. The material investigated was manufactured during the normal fabrication of a reactor pressure vessel and was made with two weld wire-flux combinations. Mechanical properties—tensile, impact, drop weight NDT, and static and dynamic fracture toughness—were determined at five locations through the thickness of the weldment. A comprehensive survey of the chemical analysis of the weldment included spectrographic and electron microprobe analysis techniques. *Babcock & Wilcox Co.*

PLANNING

EPRI Technical Assessment Workshop

PS-357-SR Special Report

This special report presents the results of a technical assessment workshop held in Chicago in September 1976. Participants from the electric utility industry and the EPRI staff discussed the analytic processes used by utilities when considering the introduction of new technologies on a power system. The workshop resulted in a better understanding of how EPRI might improve its methods and criteria for assessing the value of new technologies.

The workshop was divided into three groups for detailed discussion: program evaluation procedures, economic assessment methods, and system analysis techniques. *EPRI/Commonwealth Edison Co.*

Each month the JOURNAL publishes summaries of EPRI's most recent reports. Supporting member utilities receive copies of reports in program areas of their designated choice. Supporting member utilities may order additional copies from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303. Reports are publicly available from the National Technical Information Service, P.O. Box 1553, Springfield, VA 22151; and from Research Reports Center, P.O. Box 10090, Palo Alto, California 94303.

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