Comparing Future Options

ELECTRIC POWER RESEARCH INSTITUTE

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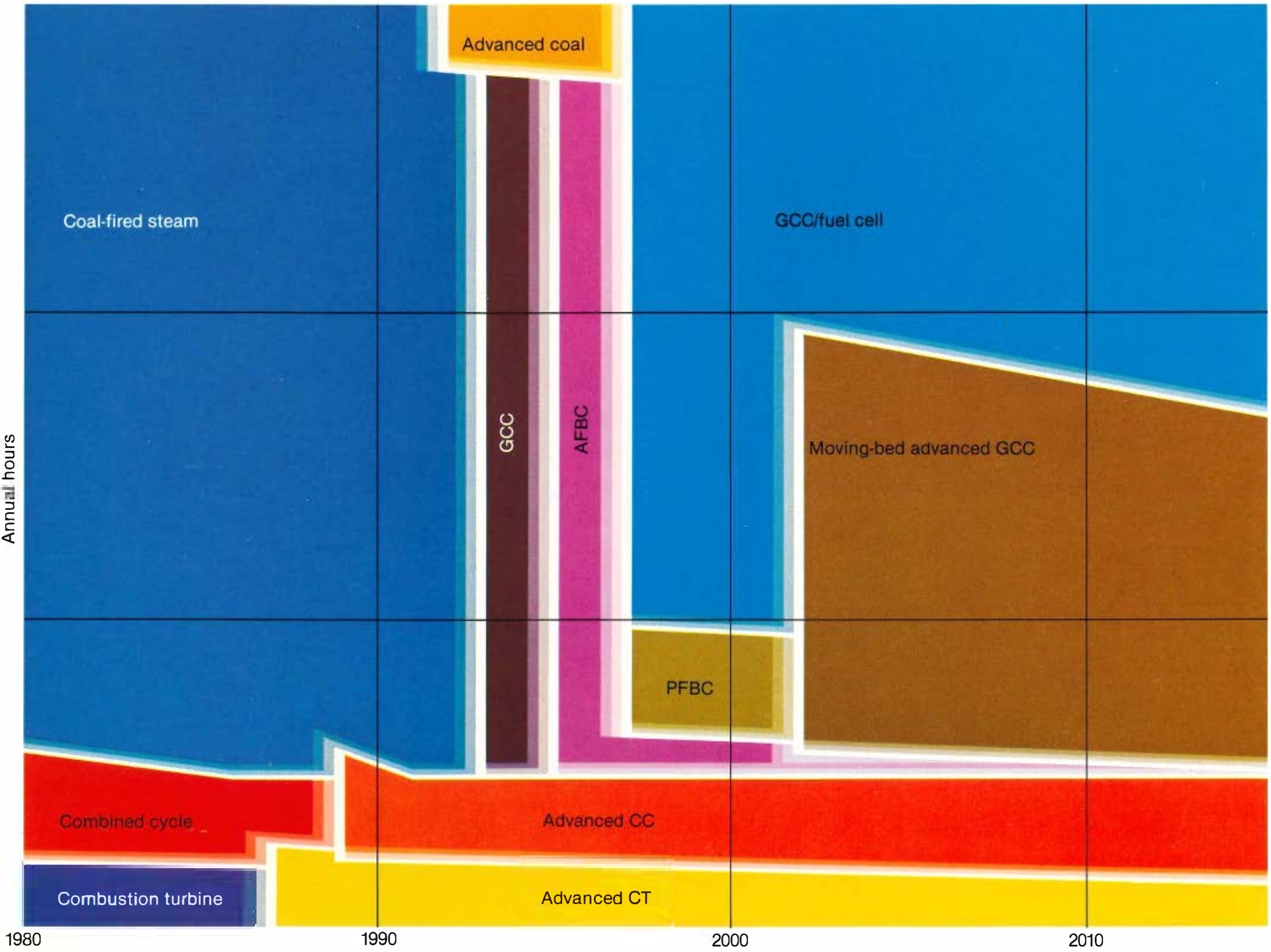

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EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

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Cover: Because new generation technologies are being developed simultaneously but at different rates, the option that is most economic to bring on-line changes with time. The diagram shows a probable succession of most-economic fossil fuel options for the East Central Region of the United States.

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The Art of Evaluation

Estimating the value of new power supply technologies, the subject of this month's cover story, is indeed an art. Like a painter, the evaluator must have a vision of something that has not yet been created, must see it complete and sense its value. Like a musician, he must follow a score—a discipline—using an accepted approach and consistent methods, but still improvising to capture the nuances of new technology. Like a writer, the evaluator must organize, synthesize, and interpret to produce a coherent result from many sources. There is no simple calculation, no superficial box score, that can replace the intense, creative integration of discipline and innovation, numbers and opinion, into a picture of the potential value of a technical development.

EPRI has many more ideas about what technologies and techniques to develop than the time and money to develop them. Judging the chances of R&D success, as well as estimating the value of new technologies, helps us decide what ought to be done, in what sequence, and with what urgency.

Many other factors are also considered before EPRI commits funds, even to promising development programs. Chief among these is what others are doing—individual utilities, equipment manufacturers, energy companies, and the federal government. If such entities other than EPRI are or should be taking on a development in a way that addresses utility criteria, we leave the task to them. If not, we take responsibility ourselves, as appropriate, in a leading or a contributing role.

Technology evaluation has been and is done in many of EPRI's research programs at various levels of detail for a variety of purposes. In our earliest days, especially during the great excitement about energy immediately after the oil embargo, we were flooded with development ideas and requests for funding. Sorting out the best ones and organizing our initial program led to many ad hoc technical and economic feasibility studies. But it became apparent that such studies should be conducted consistently so results from one would be comparable with those from another. The Technical Assessment Guide was created to meet that need and has proved useful even for the relatively simple screening studies that EPRI program managers still use to identify priority candidates for R&D.

As EPRI pursues promising technologies in earnest, the need for more detailed engineering and cost studies becomes apparent. Such studies for liquid metal fast breeder reactors and integrated gasification–combined-cycle plants have helped us to identify plant configurations that best meet the reliability requirements imposed by electric supply systems. They also point out portions of a plant or a component where technical performance is inadequate or uncertain or where costs are too high, thus directing our development effort to the key barrier problems.

Eventually, as technologies are developed, the performance of plants (or equipment) is simulated, both to understand how they would function in a real power system and to identify operating or control problems. At the highest level of aggregation, we evaluate candidate technologies in competition with one another and with improved versions of today's technology. That effort is the main focus of the lead article in this issue.

But the competitive analysis does not stand alone. It is one of several interacting and interdependent analyses. Together, they enable EPRI to expend industry R&D resources on the candidate technologies that offer the most benefit to utilities and their customers.

Richard W. Zeren

Richard W. Zeren, Director
Planning and Evaluation Division

Authors and Articles

Research investment, like any other, should be put where it will do the most good. But it is difficult to compare the prospects of electricity generation options that are technologically dissimilar and many years apart in the R&D sequence. **How Power Options Stack Up** (page 6) reviews an approach that EPRI is finding useful in setting R&D time and money priorities. For article background, feature editor Ralph Whitaker turned to George Applegren, Stanley Vejtasa, and René Loth of the Planning and Evaluation Division.

Applegren, the manager of technology evaluation, has been at EPRI since July 1979 as a loaned employee from Commonwealth Edison Co. He joined the utility in 1950 and worked successively in operations, finance, and engineering. At one time he was director of economic research and from 1973 to 1979 was system planning manager. Applegren is a Northwestern University graduate with BS and MS degrees in electrical engineering.

Stanley Vejtasa, planning engineer for technology evaluation, came to EPRI in 1976 to manage process evaluation and cost research for the Advanced Fossil Power Systems Department. From 1969 to 1976 he was with Shell Development Co., first as a petrochemicals division process engineer and later as coordinator of air pollution projects in the hydrocarbon engineering department. Vejtasa has a BS in chemical engineering from the University of Minnesota, and he earned an MS and a PhD in the same field at the University of Illinois.

René Loth, the senior technical analyst for the Planning and Evaluation Division, has been with EPRI since November 1974, successively holding responsibilities for evaluation of power technologies and research plans and for development of procedures used in those evaluations. For 11 earlier years he was with Shell Development Co. as a process engineer for petroleum and other feedstock conversion and refining programs; he came to have major responsibility for techno-economic assessments of coal liquefaction processes. From 1957 to 1963, Loth was a process and pilot plant engineer for other petroleum companies in the Netherlands and the United States. He is a chemical engineering graduate of Delft Technological University (The Netherlands).

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Construction and maintenance of distribution systems cost electric utilities about $12 billion annually; over half that figure is for the labor to dig and backfill trenches, install poles, string line, trim trees, and so forth. **New Tools to Cut Labor Costs** (page 14) is a roundup of R&D in machinery to cut back on the manhours involved. Nadine Lihach, the *Journal*'s senior feature writer, wrote the article with technical inputs from three research managers in EPRI's Electrical Systems Division.

Richard Steiner, director of the Power Systems Department since 1978, came to EPRI in June 1975 after five years with ITT Blackburn Co., where he was assistant to the executive vice president. Earlier, from 1947 to 1970, Steiner was with Union Electric Co. in St. Louis, first in transmission and distribution engineering and later in T&D construction services. He became manager of T&D development and was then named assistant to the vice president for T&D. Steiner is an electrical engineering graduate of the University of Missouri (Rolla).

Thomas Kendrew, a manager of distribution research projects since December 1977, came to EPRI after about 18 years with both municipal and investor-owned utilities. He has a BS in electrical engineering and holds California registrations as a corrosion engineer and as an electrical engineer.

Robert Tackaberry, also a distribution research project manager, has been with EPRI since February 1976. He previously held applications and marketing positions with A. B. Chance Co. (10 years) and Joslyn Manufacturing & Supply Co. (14 years). Tackaberry earned a BS in engineering at the U.S. Naval Academy.

■

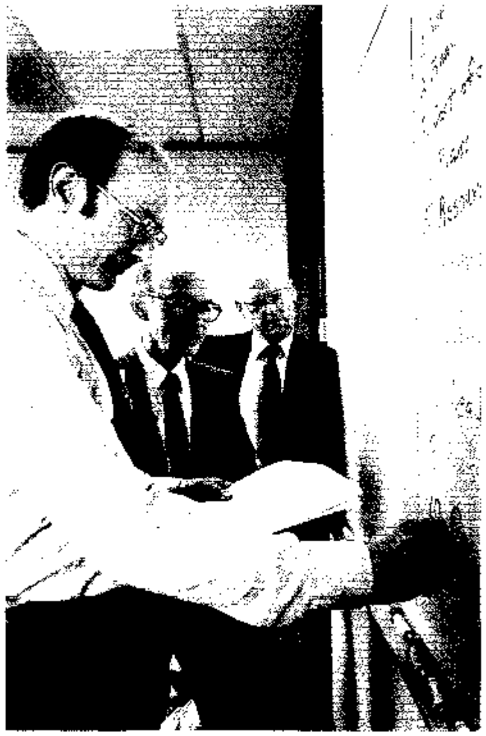
Radiography that can probe a 12-inch-thick steel section now comes in a package small and flexible enough to do in-service inspections at power plants. **Coming in Close With Minac** (page 18), by science writer Adrienne Harris Cordova, wraps up a four-year R&D effort that offers a solution to the problem of large-section component inspection and affords benefits in plant troubleshooting.

Technical guidance for the article came from EPRI's Melvin Lapides, a technical specialist closely involved with nondestructive examination research in the Nuclear Power Division. Lapides came to EPRI in July 1974, after three years as an energy systems consultant. Between 1952 and 1971 he worked in nuclear power development and in spacecraft energy and control systems for General Electric Co., Ford Aerospace & Communications Corp., and ITT Aerospace Co. Lapides has BS and MS degrees in chemical engineering from the Polytechnic Institute of Brooklyn.

■

A remedy is what counts when the traditionally corrosion-resistant copper of underground electric systems is eaten away in a matter of only months or a few years, but an explanation is the first necessity. **Protecting Copper Underground** (page 20) traces the course of EPRI-sponsored research that has produced cathodic protection systems for the bare copper neutral wires wound on thousands of miles of buried distribution cable. Ralph Whitaker, the *Journal*'s feature editor, wrote the article with the aid of EPRI's project manager and one of the principal investigators.

Thomas Kendrew has guided corrosion and other distribution research projects for the Electrical Systems Division since 1977. James Hanck, supervisor of corrosion engineering for Pacific Gas and Electric Co. since 1975, has worked in that professional specialty since he joined the utility 20 years ago. He was previously an engineering officer in the U.S. Merchant Marine, having graduated in marine engineering from the California Maritime Academy.



Vejtasa Loth Applegren

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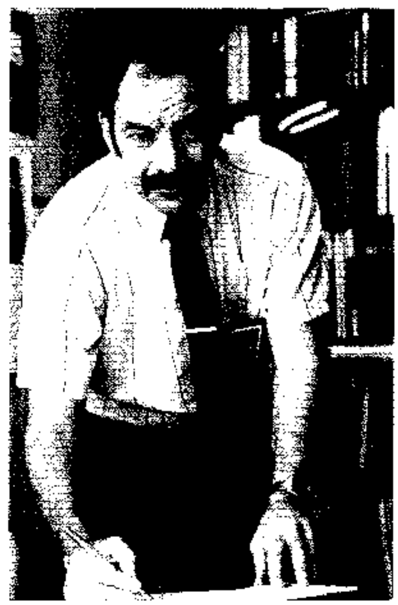


Lapides

Kendrew

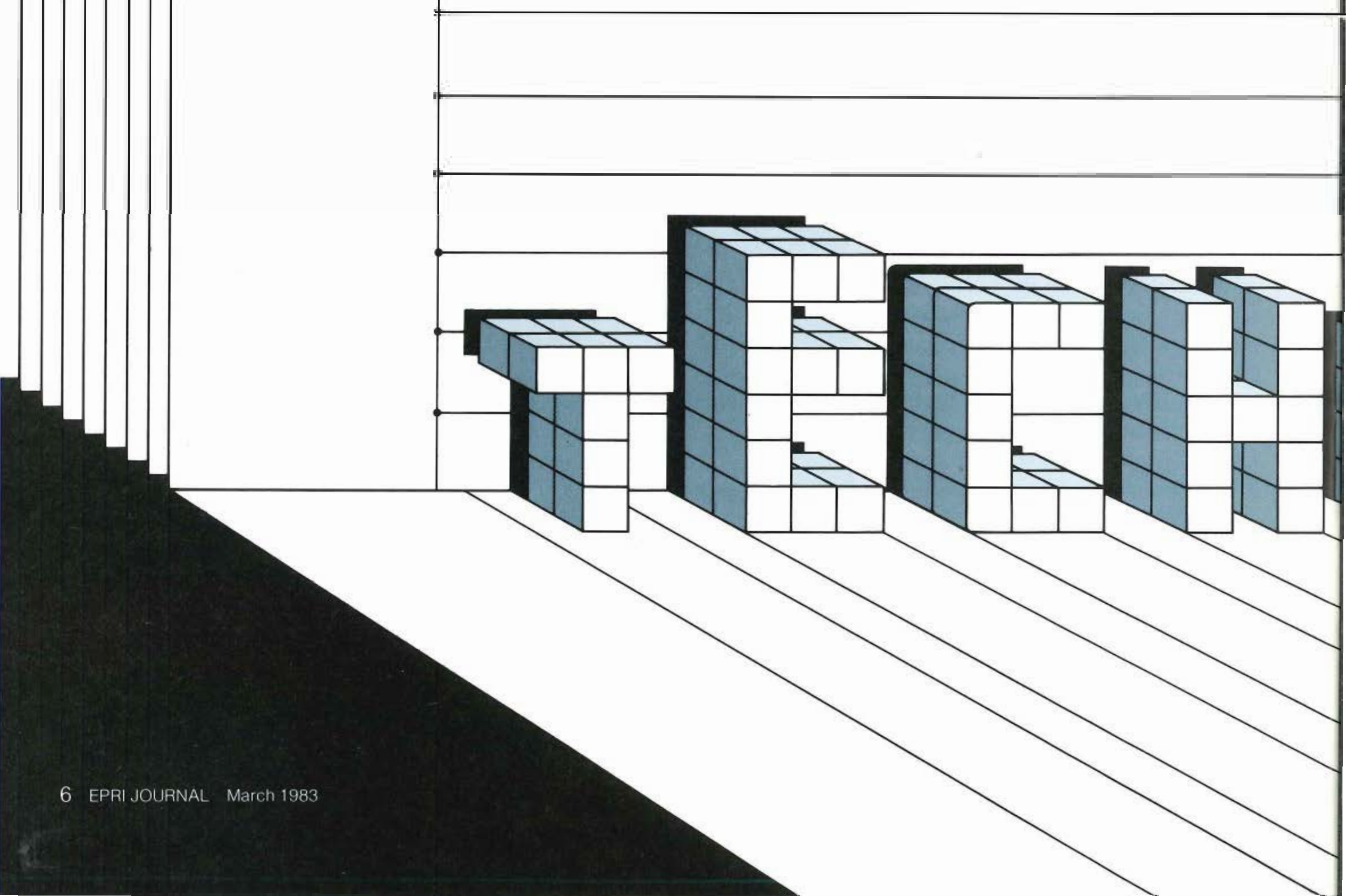
Tackaberry

How Power Options Stack Up

Twenty years from now, a gasification–combined-cycle (GCC) power plant could be the ideal choice for generating baseload electricity in the Midwest. By 2003, GCC technology should be advanced even beyond the version that is now being built for demonstration in southern California. It may well produce the lowest-cost electricity among the generating options available just after the turn of the century.

That provocative image is just one output—in very simplified form—from one application of a highly structured evaluation technique that EPRI is using to improve its R&D planning. The purpose is twofold: to identify what are likely to be the most cost-effective electricity supply technologies in future years and to determine the cost margin by which other technologies remain what EPRI calls subeconomic.

Altogether, the system of comparative economic analyses spans a 30-year period, uses six regional data bases that represent the entire United States, and involves some 35 separately defined technology options, both existing and proposed. Calculations necessary for this work are by a computer program that is aptly named COMPETE.



Richard Zeren, director of EPRI's Planning and Evaluation Division, often wishes the economic comparisons did not look so precise. "Decimal points have no place in the rankings for any year," he says. "Besides, in no way can we predict or forecast what will really happen. We have to estimate values for our variables, just like anyone else." Zeren emphasizes that EPRI performs repetitive calculations with different variables to obtain a family of projections. "We can't say that any one of them is correct, but if the same technology options show up well in several scenarios, we pay attention."

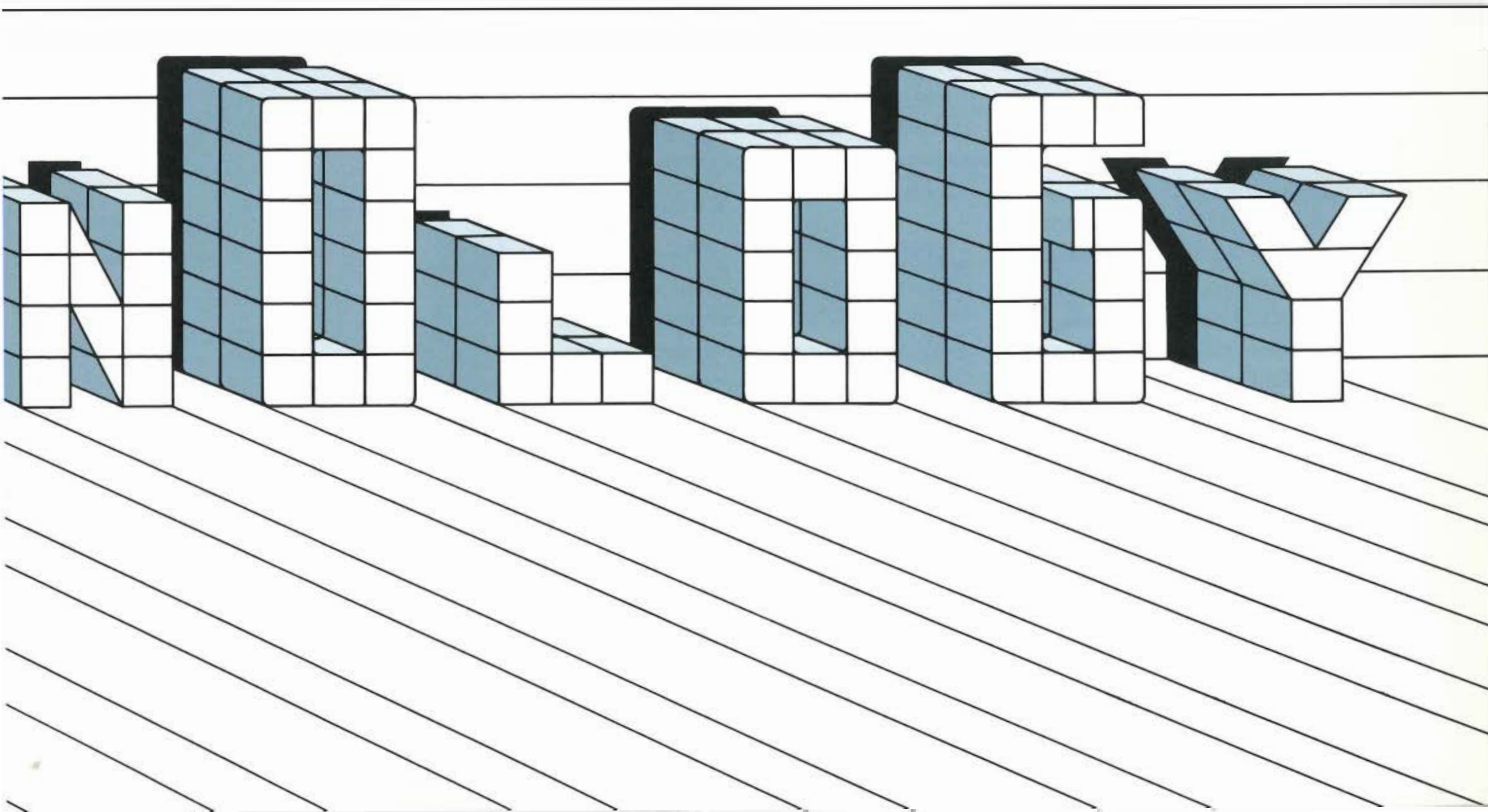
The process and its purposes

The economic evaluation process involves defining performance characteristics for each new or improved power technology and estimating the capital and operating costs of a plant accordingly. Costs differ from one region to another, a function of such variables as weather and local economics. The process also requires predicting when each option will be introduced to commercial service if existing R&D trends (funding, pace, success rate) continue.

Then, with the all-important assumed values for such economic variables as interest, inflation, and fuel escalation rates, it becomes a matter of calculation to identify for each successive year the kind of newly built plant that offers the best economy, usually expressed as the lowest levelized cost of electricity (mills/kWh) over some span of years.

The subeconomic technologies in any calculation—what Zeren calls the place and show options—are not neglected. In fact, they are perhaps subject to closer analysis than the apparent winners. George Applegren, manager of technology evaluation, explains, "We really want to know how much a subeconomic option must come down in cost so as to be essentially equal to the leader."

Electricity supply technologies, the big-ticket items of R&D, can be ranked by economic and intangible factors that take into account different capabilities, circumstances of use, and stages of development. The aim is to use consistent analytic methods to assess relative promise and identify R&D needs.



Cost variations up to 10% are attributed to uncertainty, and any option in that band is scrutinized first. A technology that has never been built cannot "win by a nose," and an apparently leading option may actually become less attractive when evaluated more thoroughly.

Many options have costs some 10–20% above the leaders. Here, EPRI staff members look for research opportunities where new equipment or new plant configurations are likely to yield major cuts in cost. Intangible factors or site-specific benefits may turn out to be controlling, but these must be evaluated separately.

Applegren adds that there is a message at the other end of any list, too. "If the estimated cost of electricity from some technology is high by 30% or more, it probably means a lot of high-risk research is needed—a virtual breakthrough. For the most part, we have to limit our own R&D efforts in such cases, pursuing high-risk ideas only if they suggest a very large cost reduction."

EPRI's ultimate goal in technology evaluation lies beyond what is possible with the COMPETE program alone. That goal is to help set R&D priorities—to help allocate money and time to the most promising technologies. And as Applegren makes clear, these are not necessarily the only front runners revealed by COMPETE.

Planning scope and criteria

Applegren's staff and the technical research groups at EPRI also monitor the electric power R&D being done elsewhere in the nation and the world, noting how much is being spent and by whom and deciding whether the preponderant R&D directions seem convergent with EPRI's. There are synergistic circumstances to be identified. Advances in steam turbines, for example, are beneficial to power technologies based on both fluidized-bed combustion and conventional pulverized-coal firing.

To the greatest practical extent, EPRI's technology evaluation process is modeled on utility decision making. But the various tools and approaches used in planning and evaluation are intended to produce a consistent, consolidated picture of R&D opportunities, not simply a list of what EPRI will undertake by itself and with what urgency the R&D will be pursued. In fact, Zeren observes, the Institute is especially mindful of the independent R&D interests and responsibilities of utility industry suppliers.

EPRI describes technology promise by four main criteria, and minimum revenue requirement (equivalent to lowest long-run cost of electricity generated) is only one of them. Another is technical flexibility—the adaptability of a plant and process to changed limitations on fuel, operations, emissions, or wastes that could come with new environmental regulation.

The third criterion is safe and reliable operation in the utility context. This includes safety for plant workers and the surrounding community. It also includes functional accommodation to transient electrical conditions and compatibility with other utility system plants and procedures.

The fourth criterion can be termed business flexibility, although it entails technical factors. It is measured by the range of feasible plant sizes, sites, fuels, and other factors that influence a utility's ability to respond to a changing business climate—in effect, its discretion in plant investment.

Consistent economic data

From the beginning of their work 10 years ago, EPRI research project managers used economic analyses to gauge the value of results foreseen or achieved. Similarly, division and Institute planners assessed the industrywide relevance of research projects or programs. But ad hoc comparisons were soon recognized for their inconsistencies in assumptions, data, and methods, and thus was born the Technical Assessment Guide (TAG),

VARIABLES IN THE ANALYSIS

Comparative analysis of technologies depends on completeness—the first trick is to include most of the economic variables that significantly influence overall electricity cost from any technology. The accuracy and precision of individual assumptions are secondary. Economic comparisons and projections can largely be done by computer, subject to the analyst's choice of several factors, in turn dependent on purpose and need. When economic factors alone preclude clear distinctions between technologies, pure judgment comes into play. Intangible factors give weight to criteria that have not been or cannot be pinned down in generic cost estimates but can be reckoned as better or worse than for a chosen reference technology.

Six regional data bases are used in EPRI evaluations of generation technology options, with information drawn from the North American Electric Reliability Council (NERC) regions shown. Climate, fuel availability, and fuel price are among the main influences of power plant selection, design, performance, and cost.

ECONOMIC FACTORS

Technologies: choice dependent on purpose of comparison and assumptions of technology availability.

Geographic region: influences choice of options (especially solar, wind, geothermal, and storage), fuel types and costs, and plant cost and performance (function of climate).

Performance characteristics: cost variation with design assumptions for plant size, efficiency, service mode (e.g., minimum load, operating period), and fuel character.

Technology introduction date: the most uncertain factor, highly dependent on the funding, pace, and success of R&D; sometimes also dependent on the timing of other technologies.

Fuel prices: oil price escalations of 0, 2, and 3% per year used as judgment alternatives by EPRI; coal price variations dependent on region, kind of coal, and specific span of future years.

Inflation: rate constant or varied for specific periods; 8.5% per year in EPRI studies.

Period of study: usually 30 years, the book life of baseload plants—often 1980–2010, but variable because possibilities until at least 1990 virtually fixed by R&D status today. (Note that comparing electricity costs for new plants in 2010 requires running book-life analyses to 2040.)

Cost levelization period: book life or any lesser period; 10 years often chosen today because that short horizon used by utility planners for better cash flow and less uncertainty.

INTANGIBLE FACTORS

Plant characteristics: compatibility of performance (e.g., load following) and output with utility system requirements for quality and controllability; also flexibility of fuel type and quality.

Resource requirements: needs for land area, construction and operating manpower (total and by skill), water supply, fuel and its storage.

Environmental compliance: waste and emissions volumes; ease of operating to meet present (or foreseen) standards for air, water, and waste quality.

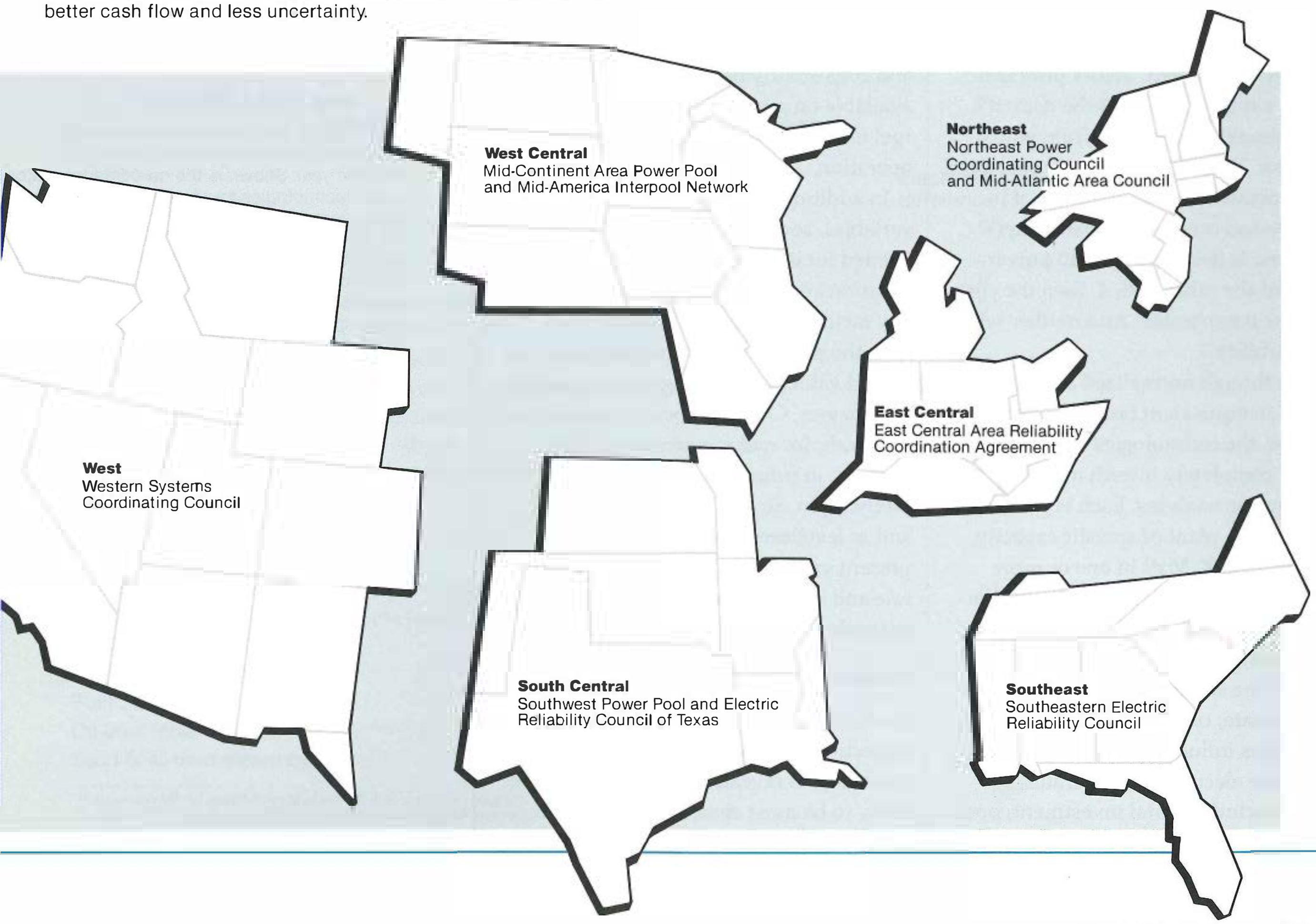
Other licensability factors: plant or process considerations that may affect actual or perceived safety or call for special regulation.

Siting considerations: the range of resource, distance, esthetic, sociologic, demographic, and construction cost factors that make site selection a major or a negligible matter.

Lead time: time spans for design and licensing, construction, and startup; important today, given very uncertain demand growth rate.

Business circumstances: the fit of a technology in a utility organization; its familiarity, its new market potential (e.g., by-product methanol sales).

Geographic applicability: severe, virtually blanket restrictions imposed by climate (solar, wind), geology (geothermal), or local policy (nuclear).



now in its fourth edition since 1977.

Method is TAG's strong point; it explains a simplified version of the revenue requirement method that utilities almost universally use. This method formalizes the derivation of annual ownership and operating costs and sets forth the conventions for making present-value comparisons.

But TAG is also a single, consistent source of specific technology data: plant size, performance and other parameters, and the consequent cost estimates for some 35 options. Representative data for major technologies in use today are included as bases for comparison, as well as for evaluating the prospects for their own improvement.

Because some data are aggregated as national averages and because many site-specific or minor judgment factors are omitted, TAG cannot be used for utility investment decisions. Consistency is its real virtue as an R&D evaluation tool. In fact, TAG is worth far more for its consistency than for its intrinsic accuracy. Applegren, TAG's principal author, explains. "It's not the data; it's the engineering approach from which data flow. Take the case of two coal-fired power plants, essentially identical in capacity and other major parameters. But if one is designed with 10 pulverizers and the other with 4, then the costs won't be comparable. And neither will the reliability."

Even though normalized and configured in equivalent fashion wherever possible, the technologies listed in TAG are not completely interchangeable in comparative analyses. Each is presented in terms of a plant of specific capacity, from 10 to 1500 MW in one or more generating units. Each plant has performance characteristics that restrict it and design assumptions that tailor it principally to one service mode—baseload, intermediate, or peaking. All these considerations influence the cost of a plant and of the electricity it generates.

Data include capital investment, operation and maintenance costs, heat rate at various loads, outage and availability percentages, and so forth. Based on current experience and knowledge, estimates of licensing time, construction time, year of first service, and plant life are also included. TAG even tallies EPRI's confidence in its information. Two ratings, each on a scale of 5, signal the stage of technology development and the level of costing detail for each option.

A feature of the plant data is that costs are keyed to one or another geographic region of the country. The regions differ in fuel prices and availabilities, load concentration, weather (affecting plant design and annual load shape), labor rates, and so on.

Comparative analysis by the COMPETE program must recognize these and other regional factors, which are represented in six regional system models compiled by EPRI. The data base for each of these models is one or two of the nine regions of the North American Electric Reliability Council. Thorough and consistently organized data are thus available on generation, transmission, fuel use, and other factors of utility operation.

In addition to plant data and regional variables, several economic factors are needed for executing 30-year analyses. Inflation and fuel escalation rates are key factors of economic context, each with the possibility of alternative assumed values or of changing values as time passes. Other factors are used as necessary for making economic comparisons in future years or for stated intervals, in current or constant dollars, and in levelized annual or lump-sum present value amounts. Carrying-charge rate and discount rate are two important examples.

Winners not clear-cut

Synthesizing the results of several cost projections involving only fossil fuel technologies reveals five options that are likely to be most competitive in the Midwest shortly after the turn of the

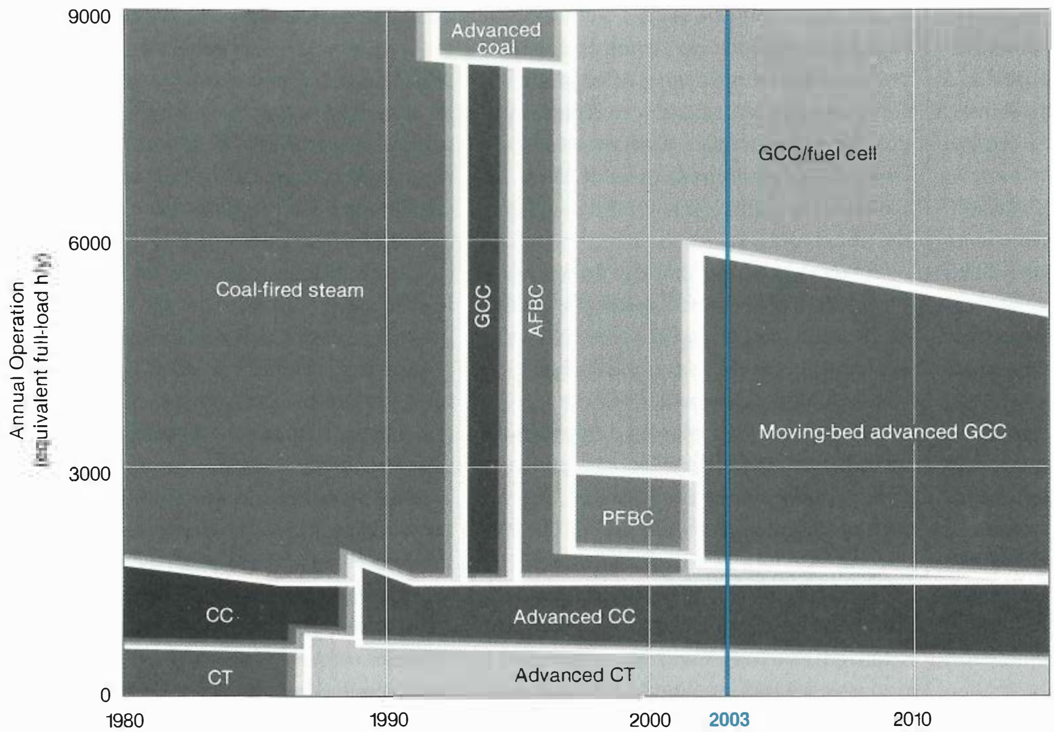
LEADERS . . .

Regional analysis yields a diagramed succession of economically preferred generation options for a particular period of time. Quite different diagrams will result when different regions, technology options, time spans, and economic variables are considered. For simplicity, this example is limited to fossil fuel technologies in the East Central Region; nuclear, solar, and wind energy options have been omitted. Comparisons are in terms of 30-year levelized cost of electricity. Leading electricity supply options are arranged on the diagram according to their most economic operating mode; *most economic* means lowest lifetime electricity cost for a new plant put online in the year shown. Vertical bands represent possible years of first commercial availability, but the underlying cost comparisons are for mature plants. The time projections are therefore optimistic—useful for comparing R&D candidates but not for planning system capacity additions. In general, horizontal and sloping bands mark annual operating periods in which costs are equal for the technologies shown immediately above and below the bands. For some technologies this boundary is set by operating limitations.

. . . and FOLLOWERS

The analysis also provides an economic ranking of competing technologies for a specific year. Shown is the outcome for major fossil technologies for the East Central Region in the year 2003; these are ranked according to the 30-year levelized cost of electricity from new plants put on-line in that year. Figures are the percentages by which electricity costs exceed the estimation for the leading options. Reducing the cost for a given option by the percentage shown would make it a leader in some service mode, depending on its operating limitations and its relative capital and operating costs.

REPRESENTATIVE ECONOMIC SUCCESSION, 1980–2010
(EPRI East Central Region)



REPRESENTATIVE ECONOMIC RANKINGS, 2003
(EPRI East Central Region)

	Electricity cost difference (%)
Baseload options	
Entrained gasification–combined cycle with fuel cell (GCC/fuel cell)	0*
Moving-bed gasification–combined cycle with 2600°F (1427°C) turbine (moving-bed advanced GCC)	0*
Atmospheric fluidized-bed combustion (AFBC)	0*
Pressurized fluidized-bed combustion (PFBC)	+1
Entrained gasification–combined cycle with 2600°F (1427°C) turbine	+10
Entrained gasification–combined cycle with 2000°F (1093°C) turbine (GCC)	+12
Advanced coal-fired steam cycle (advanced coal)	+14
Coal-fired steam cycle (coal-fired steam)	+20
Coal-fired steam cycle with regenerable scrubber	+22
Gasification–steam cycle	+25
Intermediate and peaking options	
Advanced oil-fired combustion turbine (advanced CT)	0*†
Advanced oil-fired combined cycle (advanced CC)	0*
Oil-fired combined cycle (CC)	+5
Advanced fuel cell	+11
Fuel cell	+17
Oil-fired steam cycle	+18
Solid SRC-fired steam cycle	+43

*Most economic for specific range of annual duty shown on diagram.
†A unit of 1980–1985 design would be even more economic if intended only for emergency standby (no planned duty).

century. This is on economic bases alone: the lowest levelized annual cost of electricity.

There is an illusory certainty about these projections. Individual options take on precision partly because of the descriptive detail needed to distinguish them as R&D candidates and to differentiate their major attributes of performance and cost. An example is the advanced GCC power plant suggested earlier as ideal for the Midwest in 2003. It could be either of two designs elaborately described in TAG. One will have familiar gas and steam turbines like combined-cycle plants today. But its fuel gas will come from a coal gasifier that is only at the pilot plant stage now. Also, the gas turbine will run at 2600°F (1427°C) for better efficiency than its 2000°F (1093°C) counterpart of 1983.

Or this not-so-distant future plant may have no gas turbine at all. Instead, its gasifier will feed a high-temperature molten carbonate fuel cell section that produces direct-current electricity and also delivers 1000°F (538°C) heat into a steam turbine supply.

These two GCC plants are only concepts today. Their status in the R&D pipeline allows EPRI to estimate that plants could be introduced into commercial service at about the turn of the century. But timing is the weakest part (and consistently so) of all these projections. The dates are those of optimistic first service, but the costs are those of mature plants, perhaps the third or fourth of a design, incorporating economies that come only with experience. This optimistic skew is tolerable in strictly comparative analyses for R&D planning, but it is the strongest reason that the results cannot be treated as forecasts.

Another comment about the technology cost estimates comes from Stanley Vejtasa, the EPRI planning engineer who has compiled much of the technology data for TAG and for analytic screening by COMPETE. He cautions against reading too much into comparisons between technology options that are at an early stage of development. "But we can learn a lot from the costs of subsystems within any one technology," Vejtasa says. "They help show strong and weak points. A very high cost estimate for one component or subsystem can signal an unknown or uncertain area, a place where R&D has to be focused if costs are to be brought down. It tells us where the opportunities are."

Vejtasa points out that the preferred configuration for a GCC plant changed dramatically between 1975 and 1980 as economic evaluations by EPRI's Advanced Power Systems Division revealed successive preferred designs and incremental R&D needs. He concludes, "These cost estimates help shape the path of technology development."

Evaluating intangibles

Comparative economic analyses deal in a consistent manner with the cost criterion, but what they seem to reveal must be double-checked by review against other criteria. EPRI developed an analytic framework for this purpose a number of years ago. Now it is being revised and improved by Zeren's staff, working cooperatively with advisers from the utility industry and with specialists from various technology R&D programs in EPRI's six technical divisions.

Intangibles analysis is the bridge from identification of the apparently lowest-cost technologies to the thoughtful selection of the most promising. It is useful in clarifying economic rankings, coming into play particularly when the percentage intervals between the costs of options are less than the uncertainty of those costs.

EPRI posits some 40 factors that influence selection of a power technology but are intangible to some degree. "The challenge," says Applegren, "is to quantify what can't be quantified." Asked whether he means "can't be" or "hasn't been," he quickly says, "Both, actually. It's mostly a matter of our not yet knowing how to quantify some factors—or choosing not to because they are too site-specific even for regional modeling."

The 40 factors are grouped under headings such as resource requirements, environmental compliance, siting considerations, lead time, business circumstances, R&D aspects, and commercialization aspects. These headings are not rigorously parallel in logic or free of overlap, but their organization and use are still evolving.

Clearly, the means of evaluation is itself a matter of judgment. So far, EPRI's procedure uses a reference power plant and a simple numerical scale. Two established power technologies have been chosen for the purpose: a conventional coal-fired plant with flue gas desulfurization (lime/limestone scrubbers) for baseload comparisons, and a distillate-fired combustion turbine plant for peaking demand comparisons. (So as not to foreclose the future for these technologies, advanced versions of both are included in the evaluation scheme and are compared with the benchmark versions.)

When making a specific comparison, the EPRI evaluator assigns a value of +1 (or −1) to each factor if it seems significantly better (or worse) than its counterpart in the reference technology. When the factor is much better (or worse), the evaluator uses +2 (or −2); when the distinction or its implication is negligible, the rating is 0.

How judgments evolve

For the sake of consistency, one analyst evaluates as many factors and technology options as possible. But there are trade-offs. No single person's experience spans all the factors of all the candidates. In addition, redundant evaluations are needed to compensate for unrecognized biases. Therefore, formal analyses of intangibles will call for several evaluators, each of them judging different (but overlapping) groups of technologies. Sharply different perceptions of any one technology can then be resolved.

Much of the analytic work with intangible factors has been done by or under the guidance of René Loth, EPRI's senior technical analyst in the Planning and Evaluation Division. Loth cautions against "counting a factor twice," explaining that analysts must be watchful for technology attributes that can be linked to more than one heading. For example, a technology requiring relatively little water for scrubber operation rates a resource requirement credit for that. The same technology may thereby produce less sludge; does it rate an environmental compliance credit accordingly?

Loth also realizes that intangible factors can sometimes be converted into economic factors. "Sulfur dioxide emissions can be reduced by using different scrubbers; water use, by using dry cooling—each at the expense of a greater capital cost for the plant." That cost is calculable and could be included in the economic analyses, but doing so would tend toward an unwieldy number of technology variants, as well as unwarranted specificity.

Some of Loth's thinking illustrates the evolution of intangibles analysis. Speaking of relative fuel requirements, Loth says, "A technology with a lower heat rate could reduce the rate of fuel resource depletion and, therefore, its price escalation. Of course, this is true only if the improvement is used widely enough to affect the fuel market.

"Among coal-fired options," Loth goes on, "heat-rate improvements of 400–700 Btu/kWh are assigned a +1 rating and differences of 800 Btu/kWh or more, a +2 rating. In early evaluations, we assigned similar credits to fuel cells and combined-cycle plants relative to combustion turbines. I now believe this was incorrect; improved heat rate shouldn't yield a fuel resource credit for any oil- or gas-fired plant."

Applegren, his EPRI colleagues, and their industry advisers rely on methodology to lend consistency to their judgments, especially in dealing with intangible factors. "We're developing a sensible, repeatable way to help balance the expenditures of a lot of R&D money among a lot of promising candidates," he says.

When all is said and done, however, the intangibles analysis can lead to a paradoxical conclusion. Vejtasa uses the examples of GCC and atmospheric fluidized-bed combustion (AFBC) technologies, both in comparison with the coal-fired plant used as reference. "GCC gets a lot of +1 and +2 ratings, where AFBC gets zeros," Vejtasa says. He explains that the ratings reflect GCC's minimal resource requirements, improved performance, environmental benefits that make for easier siting, and considerable technical flexibility. "But those pluses all stem from the basic fact that GCC is, overall, a new technology, in some respects radically so for our industry. For just that reason it may be hard to commercialize."

The many zero ratings of AFBC, however, reflect its many points of similarity to coal-fired generation. "Because it is similar," Vejtasa concludes, "it is also familiar. It's potentially an easy technology for utilities to adopt."

The paradox is yet to be resolved. Perhaps it will vanish at the level of specific plant comparisons in real-world utility planning.

Refinement and use

Technology evaluation seems constantly to proceed, or at least to pull, in opposite directions: toward tidy specificity and focus on the fewest possible hard choices in the COMPETE analyses and also toward comfortably hedged generalization and diversity among many alternatives in the conclusions and recommendations drawn.

Superficially, the one looks more efficient and economic, but the other looks safer and smarter in an uncertain world. Applegren, a longtime utility system planner now on a loan assignment to EPRI, emphasizes the latter: "A utility dares not go with a single technology if it can possibly avoid it." Zeren adds, "The uncertainty is greater in the R&D world, so it's even more important not to narrow down too soon."

This circumstance clearly influences the scope of EPRI's evaluations: the number of electricity supply options considered, the variety of factors used to distinguish them, and especially the use of the rankings that result. It is customary to look for winners. EPRI's deliberate study of place and show technologies represents judicious contingency planning for an industry that has many regional and local differences and, because of many uncertainties, must avoid putting all its eggs in one basket.

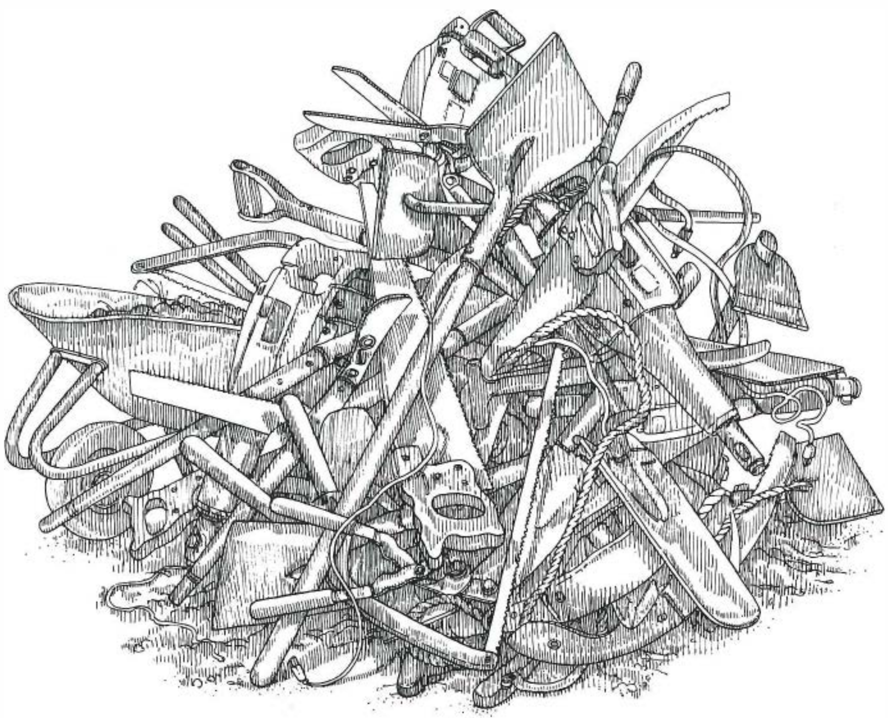
Even in their present form, EPRI's technology evaluation results can be used in generation expansion studies on computerized regional and system models, each with its distinctive load pattern and mix of generation types. From these studies, the extent of market penetration can be estimated for various technologies. This affords some measure of industrywide benefits.

Down the road, technology evaluation techniques can perhaps be used to assess the benefits actually achieved from work along some R&D avenue selected earlier. Zeren, Applegren, Loth, and Vejtasa also foresee adapting their methods to transmission and distribution systems and to technologies for electricity end use.

What weight does technology evaluation carry in EPRI's program decision making today? Applegren's expression says he wishes there were a simple answer. There is not. He can only observe, "These approaches must still be considered new, growing in acceptance in the industry, among our advisers, and here in the Institute itself. Considering all those groups together, technology evaluation is a systematic attempt to improve the way EPRI goes about its work." ■

This article was written by Ralph Whitaker. Technical background information was provided by George Applegren, René Loth, and Stanley Vejtasa, Planning and Evaluation Division.

New Tools to Cut Labor Costs



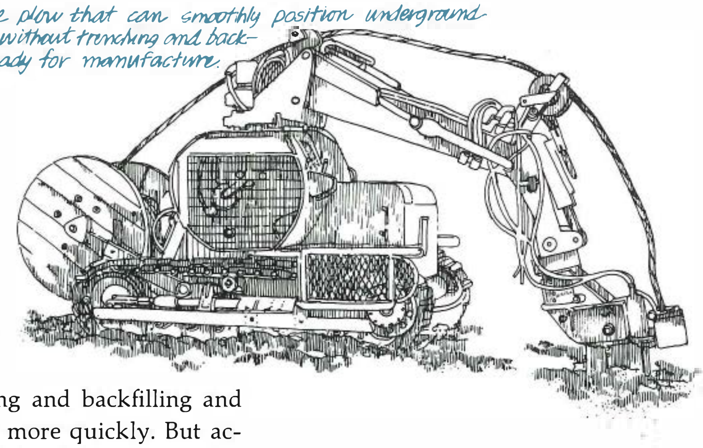
Construction and maintenance of electricity distribution systems are full-time jobs that cost utilities and their customers some $12 billion every year. New labor-saving devices under development at EPRI will reduce that bill significantly.

Wherever there are electric utility distribution systems, there are also workers digging and backfilling trenches, installing underground cable, trimming back trees that encroach on overhead lines, raising new poles, and stringing new wires. The relentless construction, repair, and maintenance of the hundreds of thousands of miles of lines that crisscross the country go on day after day and cost about $12 billion each year. Well over half of this amount goes for labor costs, but it doesn't have to be that way. A workforce of devices is being readied to reduce the labor required and cut utility customers' electricity bills in the bargain.

Inevitable job, avoidable cost

The tools and the techniques to go with them are being developed in EPRI's Electrical Systems Division. An advanced cable plow that can smoothly position underground distribution cable is almost ready for manufacture. Two concrete cutters that can eliminate jackhammer work are under development. So are a steerable, small-diameter borer that can run under pavements and private property without disturbing the surface, a cable follower that can replace failed cable with minimal excavation, and devices that will cut back on tree-trimming costs. With EPRI assistance, growth retardants for a variety of trees have recently been registered by EPA. And a project to develop a device that can dig utility pole holes in rocky soil is about to begin. "Research in the ES Division has produced a whole group of new products that can be used to reduce construction, repair, and maintenance labor on the utility distribution system," asserts Richard Steiner, Power Systems Department director.

Consider the case of underground distribution. To install underground distribution cable, a trench is usually dug, the underground cable placed in it, and the trench backfilled. The job is ordinarily done with trenchers or backhoes and is by no means speedy. Several cable plows have been manufactured that elim-



An advanced cable plow that can smoothly position underground distribution cable without trenching and backfilling is almost ready for manufacture.

inate the trenching and backfilling and thus install cable more quickly. But according to EPRI Project Manager Thomas Kendrew, these plows have had problems with cable feed and tension, ground disturbance, and maneuverability. They also require expensive, time-consuming mobilization and cleanup. EPRI and contractor Oretek Laboratory, Inc., have developed a cable plow that is lightweight, versatile, maneuverable, and powerful—and capable of a continuous plowing operation to 36 inches deep in all plowable soils, possibly deeper in less difficult soils.

The new plow, called the Scorpion, concentrates the power of its hydraulic drive units on the plow blade, which features several innovations over earlier blades. A highly efficient vibratory mechanism is contained in the blade, rather than above the blade as in conventional vibratory plows, so much more vibratory energy is transferred to the ground. This increases efficiency and reduces wear on the equipment. The plow also features a high-pressure, low-volume water-jet system on the leading edge of the plow blade that helps soften, cut, and lubricate the soil as the blade advances.

The plow's two cable feed shoes are another unique aspect of the equipment. One shoe is used to install a single cable. The other is used to pull multiple cables; thus a distribution loop may be pulled in one cable while leaving the plow blade, feed shoe, and other cables in the ground.

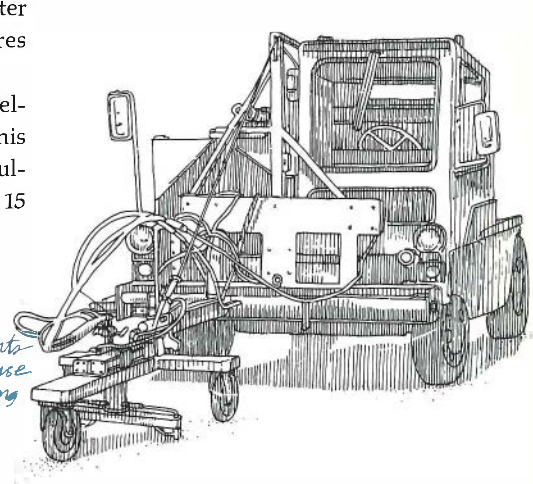
The cable plow is now undergoing field tests at Douglas Electric Cooperative, Inc. (Oregon), and if the tests prove successful, the plow will be considered ready for manufacture. A nonexclusive licensing agreement has already been reached with Gerlinger Industries Corp. of Salem, Oregon, for manufacture and distribution of the plow.

Sometimes workers must remove concrete or asphalt pavement before trenching operations can begin. Jackhammers are usually used to break through the pavement, but they require considerable amounts of labor and time in addition to being noisy. Two mechanized concrete cutters being developed by EPRI should help reduce labor and operating costs, as well as noise, according to Project Manager Thomas Rodenbaugh. The first prototype cutter developed was a vehicle-mounted device by Flow Industries, Inc. It used high-pressure water jets in an attempt to slice through pavement. The latest, more effective version of this cutter attacks pavement with mixtures of water and abrasive particles at water pressures of about 35 ksi (241 MPa).

The second cutter is now under development by Fluidyne Corp. Because this cutter is trailer-mounted and uses multiple low-pressure water jets (about 15 ksi, or 103 MPa) and less abrasive material, it has the potential to reduce concrete-cutting costs still further.

Where highways, landscaping, and similarly established features prevent utility crews from trenching to lay new distribution cable, small-diameter underground boreholes must be made. Small borers that can make the necessary boreholes are now on the market, but these small borers lack steering systems, according to Kendrew. If the borer is deflected from its intended course by rocks or other underground obstacles, the borer may go so astray that workers have to cut off the supply hoses, abandon the borer, and try again with a new borer. These borers are also limited in the distance they can bore. The entire operation ends up being costly and labor-intensive.

EPRI and contractor Flow Industries are currently developing a steerable borer. The device's electronic steering system can sense changes in the borer's course and relay the information back to the operator, who can then manually correct the course. Improved versions of the borer may also incorporate a microprocessor that can keep the device on course. Besides being steerable, the borer can travel longer distances than its conventional counterparts and can penetrate difficult soils with the aid of water jets. A prototype borer has been built and is expected to be tested this year.



Two concrete cutters that can eliminate jackhammer and saw work on pavements are under development. Both systems use pressurized water jets to do their cutting.

A cable follower that can replace failed cable with minimal excavation by using the original cable as a guide will be field-tested this spring.

Taking the borer one step further, EPRI and Flow Industries are also developing a cable follower that replaces old or failed cable; it will use the original cable as a guide and therefore not disturb the surface. This device employs some of the borer's technology, but dispenses with the steering system. Grippers within the follower hug the old cable, enabling the follower to advance on the cable while water jets cut and remove the soil ahead. The old cable can then be withdrawn from the tunnel and the new cable pulled in. Once again, this device eliminates the need for excavation (except at the start and end of the run), and much of the labor requirement along with it. The cable follower will be field-tested this spring; if the tests are successful, it should be ready for commercial manufacture before the end of 1983. The follower is already qualified for use in sandy and loamy soils, and upcoming tests will be in hard-packed clay soils.

Trimming trees and costs

In addition to using large amounts of labor to work on underground distribution systems, utilities also expend large amounts of labor on overhead distribution systems. One overhead operation with high labor costs is tree trimming—branches near overhead distribution conductors must be trimmed regularly to prevent the branches from contacting the conductors and causing fires or outages. As trees must be trimmed on the average of every one to three years and there are countless trees lining overhead distribution rights-of-way, the manpower requirements for tree trimming are considerable.

Trimming is done by utility crews or by tree service companies under utility contract. Trees along streets and highways are usually maintained by two- or three-man crews working from bucket trucks; trees in more inaccessible areas, such as back lots, are normally maintained by three- or four-man crews who climb the trees with the help of rope, safety belts, snap hooks, and climbing hooks. Once up in the tree, trimmers use saws, shears, axes, and pruners to trim the tree.

Recent EPRI research indicated that much of the trimming job consists of setting up equipment in trucks and trees. The ES Division was convinced that there had to be a more effective way of doing the job and initiated a project to design and produce improved tree-trimming equipment that would require less setup time and would reduce operator fatigue. In all, 40 new approaches were identified. Some of the concepts—such as laser beams and high-pressure water jets—were discarded as too impractical, but the project did identify five strong prospects for immediate consideration: a pantograph support, boom-mounted tools, a mobile platform lift, a servo-assisted pole saw, and a cut/bundle/chip vehicle.

The pantograph system is the most attractive of the five for near-term development, according to Project Manager Robert Tackaberry. The system would support pole-type pruning tools by means of counterbalanced springs or other torque-producing devices. This would reduce operator fatigue and permit the use of longer, heavier, and higher-horsepower cutting tools. The pantograph would also extend the reach of pruning equipment. Because the device can be adapted to existing utility bucket trucks, it has a good probability of success with utilities. EPRI has recommended the device for immediate development and could contract as soon as this summer for the design and construction of a prototype. The prototype could be completed and tested within one or two years from project start.

The other tree-trimming concepts identified by the project may be suitable for later development. The boom-mounted tools would replace the bucket in existing bucket-truck booms with a series of interchangeable tools. Again, this device would permit the use of larger tools with higher horsepower ratings. Another concept, the mobile platform lift, is a motor-driven, self-propelled, bucket-type vehicle. Vehicle steering and bucket positioning would be controlled by bucket-mounted hydraulic controls. The servo-assisted pole saw concept consists of a motor-driven hydraulic power supply connected to a pedestal-supported pole saw, which is positioned with the help of the hydraulic system. The device would be operable from the ground with minimum effort. The servo-assisted power saw, the boom-mounted tools, and the mobile platform would each require about two or three years to develop.

The cut/bundle/chip vehicle comprises a boom-supported cutter and bundler and a truck-mounted chipper. The vehicle would hold and cut tree limbs, accumulating a bundle of limbs before transferring them to the chipper. Unlike other tree-trimming concepts, this vehicle would address the laborious operation of lowering limbs, piling brush, and feeding the chipper. These jobs are beyond the scope of the present project, but they might have great potential for future labor savings. The cut/bundle/chip vehicle would take from three to five years to develop, the longest time of all five concepts.

Another promising strategy for reducing tree-trimming labor costs is to prolong the period of one to three years between tree trimmings by slowing down tree growth. A number of commercially available agricultural compounds inhibit plant growth, and in 1973 EPRI began a project to determine how these growth inhibitors could be used on trees near utility distribution lines.

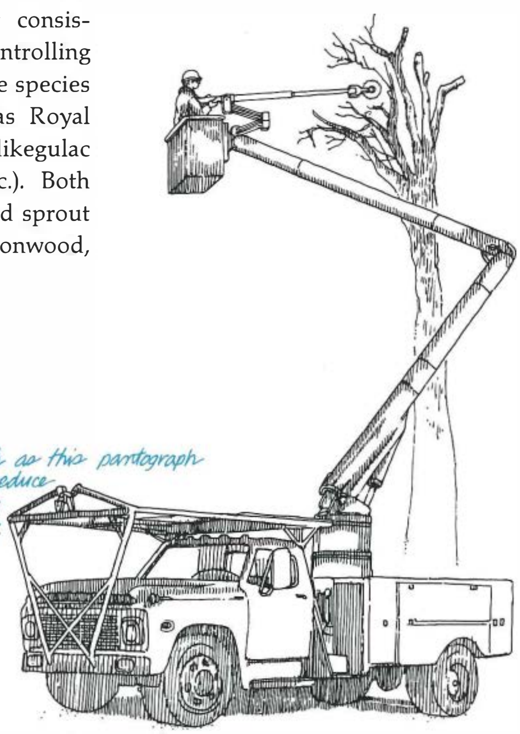
About a dozen prospective compounds were screened by the U.S. Department of Agriculture under EPRI contract. Greenhouse, laboratory, and field studies determined that the most consistently effective chemicals for controlling growth over a wide range of tree species were maleic hydrazide (sold as Royal Slo-Gro by Uniroyal, Inc.) and dikegulac (sold as Atrinal by Maag, Inc.). Both compounds effectively controlled sprout regrowth in big leaf maple, cottonwood, eucalyptus, London plane tree, silver maple, and sycamore; dikegulac also controlled growth in shamel ash, water oak, hackberry, and Norway and red maples. These retardants were able to extend the tree-trimming cycle by one or two years without killing or discoloring the trees. Experiments on reinjection showed renewed growth control without cumulative phytotoxic effects.

Both Slo-Gro and Atrinal have recently received supplemental EPA registration labels for use as tree growth retardants with an injection system on the above species. A portable, air-powered injection system has been developed by EPRI that treats the tree directly with the chemical solution, thereby avoiding spraying, which can create chemical drift and instigate complaints from neighbors. EPRI has also developed information on how the chemicals can be best applied, taking into consideration such variables as tree trunk size, tree canopy size, moisture conditions, and season of application.

Another labor-intensive job for overhead distribution crews is setting utility poles in rock. The vast majority of poles are set in earth with the help of boom- or bed-mounted mechanical augers called pole-hole diggers, but this equipment cannot easily penetrate rocky soils. Under such difficult conditions, pole holes may have to be excavated with jackhammers or by drilling and blasting. Holes dug with jackhammers cost up to eight times more than holes dug with augers; holes dug by blasting can be as much as thirteen times more expensive. Blasting is also an unacceptable technique for populated areas.

EPRI will attempt to find a way of digging pole holes in rock for at least half the present cost with only a two-man crew. Advanced techniques, such as high-pressure liquid fracturing or high-pressure water jets, might be the solution, according to Tackaberry, and a three-to-four-year project to design, build, and demonstrate a prototype for digging pole holes in rock is expected to begin later this year.

Digging pole holes, excavating trenches, installing cable, and trimming trees all require many hours of labor. They may seem like small jobs, but when multiplied by the miles upon miles of distribution lines in the United States and by the number of times many of these jobs must be repeated again and again, they add up to a big budget item for electric utilities and ultimately for utility customers. But in the next few years, the cable plow, the concrete cutter, the cable follower, the borer, the tree trimmers, and growth retardants will all contribute to reduced distribution costs for utilities—and for utility customers as well. ■



Improved tree-trimming devices, such as this pantograph support for pruning tools, could reduce setup time and operator fatigue; development will begin this year.

Further reading

New Methods and Chemicals to Control Regrowth in Trees. Final report for RP214-2, prepared by U.S. Department of Agriculture, September 1982. EL-2569.

Development of Improved Tree-Trimming Equipment and Techniques: Phase I. Final report for RP1780-1, prepared by Asplundh Environmental Services, September 1982. EL-2599.

This article was written by Nadine Lihach. Technical background information was provided by Thomas Kendrew, Thomas Rodenbaugh, Richard Steiner, and Robert Tackaberry.

COMING IN CLOSE WITH MINAC

R E S E A R C H A P P L I C A T I O N

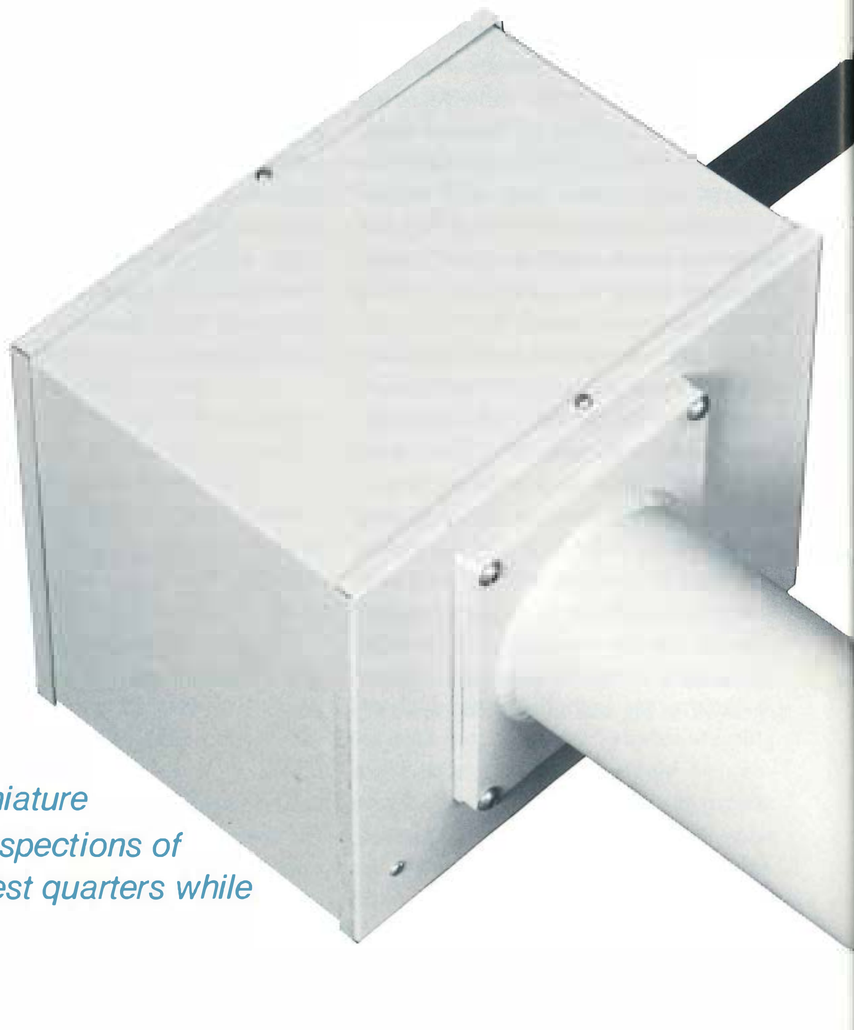
Small, portable, and powerful, this miniature linear accelerator can perform X-ray inspections of thick-section components in the tightest quarters while the plant is in operation.

Regulatory requirements for nuclear power plants have created stiff technical challenges for the utility industry, not the least of which is mandated inspection of thick-section stainless steel components. Until recently, no technology was both flexible enough for in-plant use and powerful enough to nondestructively examine the internals of components up to 30 cm (1 ft) thick without exposing plant personnel to unacceptable levels of radiation.

An EPRI R&D effort begun in April 1977 has produced a technology that solves many problems raised by current requirements and that promises cost savings as well. Minac, a miniaturized linear accelerator system developed by EPRI, draws on linear accelerator technology to perform in-service radiography of many generating plant components, including pipes, valve bodies, and pumps. Through increasing the radio wave frequency used by conventional linear accelerators, researchers made it possible to generate a high output of high-energy X rays in a device five times smaller than most linear accelerators. Whereas on a conventional accelerator the radiation head alone weighs approximately a ton (900 kg), the entire Minac accelerator weighs less than 700 lb (315 kg). The result is a device small enough to use in plants inaccessible to larger inspection equipment.

Indeed, Minac makes possible inspections and diagnostic activities technically out of reach before its development. While manufacturers of nuclear plant components have depended on sophisticated industrial radiography operating at 4–25 MeV to ensure the construction integrity of thick-section components, the technology has been too large and heavy to use in the field to identify possible service deterioration. Thus, in-service inspections have relied on radioisotopes for the radiation source, which generally have limited output intensity and cannot penetrate components thicker than 15 cm (6 in). The resulting long exposure times and the continuous radioactivity pose some concerns about controlling workers' exposure to radiation.

The impetus for improved inspection capability has been Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, which calls for in-service volumetric examination of such thick-section components as reactor coolant pumps, pressure vessel nozzles, and valve bodies. Four of the five field applications undertaken by EPRI so far have focused on ASME-mandated pump inspections. However,



another benefit of Minac development, which in fact may become one of its major contributions, is its use in diagnosing the source of power generating losses during normal plant operation. Early experience suggests that this application could well result in major time and dollar savings for utilities.

Minac-3, operating at 3.5 MeV, was in field use only four years after the concept was developed. EPRI had three partners in the first field inspection at Rochester Gas and Electric Corp.'s R. E. Ginna Nuclear Power Station in April 1981. Schonberg Radiation, Inc., manufactured the hardware, which consists of a radiographic head, a modulator power supply, and a control console; Southwest Research Institute developed application specifications; and RG&E performed the field engineering and developed the procedures and supporting equipment for the inspection.

Using a remote manipulator developed by the Rochester utility, inspection personnel lowered the Minac head into pump bodies within the containment vessel and successfully examined 34 m (100 linear ft) of welds in five days. The control unit was operated 64 m (200 ft) from the inspection site behind shielding, minimizing exposure of inspection personnel to radiation.

The success of this first test was matched by productive pump inspections at Wisconsin Electric Power Co.'s Point Beach plant in October-November 1981, Florida Power & Light Co.'s Turkey Point plant in January 1982, and Carolina Power & Light Co.'s H. B. Robinson-2 plant in April 1982. In all cases, radiographic exposures met regulatory quality specifications and obtained better than 1% sensitivity.

Minac's second field application, at Consolidated Edison Co. of New York, Inc.'s Indian Point-2 plant in July 1981, is the one that suggests Minac's diagnostic potential. Believing that an interruption of steam flow was affecting the plant's power output, Con Ed requested a Minac inspection of a series of valves. Although the inspection was complicated by high temperatures and its location outside containment walls, Minac's on-off capability, tightly collimated beam, and output control (allowing a slow buildup of power) minimized radiation exposure and caused minimal interruption of normal plant operation. The exposures revealed that two partially closed valves were causing part of the plant's power loss. Repair of the valves was performed during a previously scheduled outage, and the ability to conduct the inspection while the unit was in operation represented a savings of 20 MW of power.

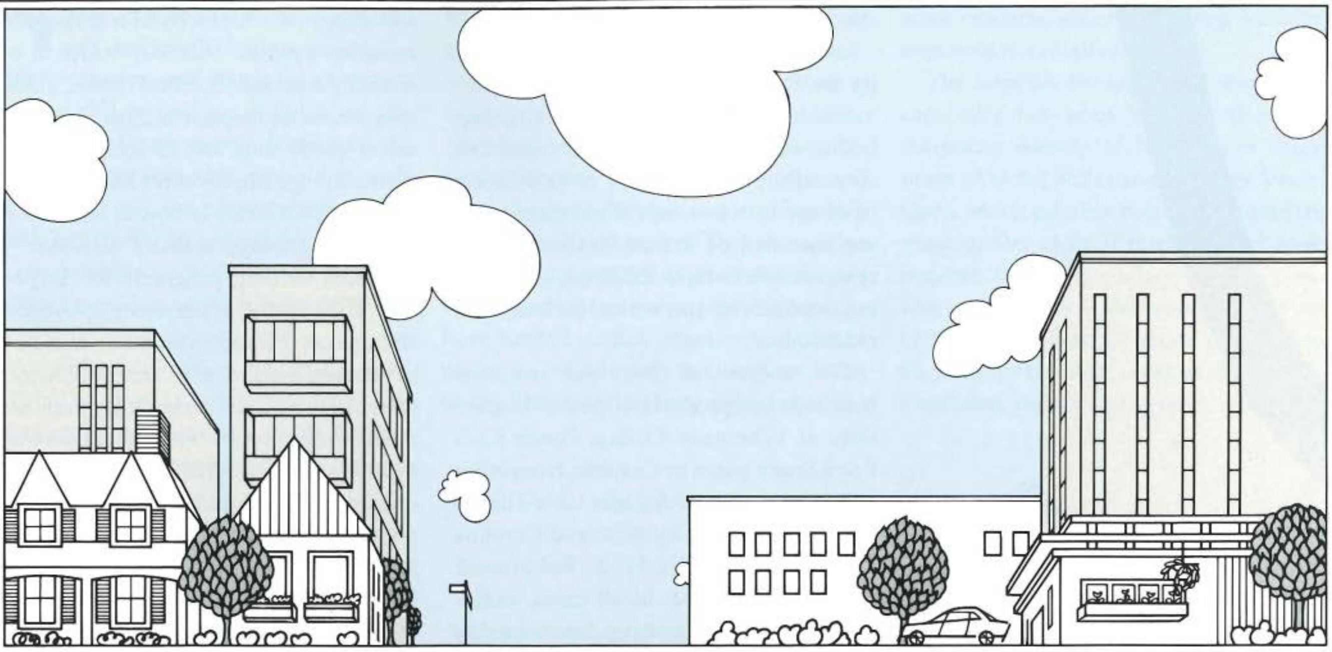
EPRI's Nondestructive Evaluation Center became involved in Minac's continued development in the summer of 1981 after the inspections at RG&E and Con Ed. Recognizing a need to improve the method of transporting and setting up Minac equipment, the NDE Center obtained a trailer and designed it to store and transport the complete system. This van, which is essentially a portable control center, allows easy access to inspection sites and minimizes costly time lost in setting up and dismantling equipment for an inspection.

The NDE Center is now at the hub of Minac technology transfer activities. It conducts training programs for inspection and utility supervisory personnel and makes Minac equipment available to interested utilities. In addition, it continues to investigate technologic improvements in the system. Such developments include a new high-quality film processor, upgraded Minac and manipulator components, and methods of varying the scope and configuration of the beam. EPRI researchers are currently developing a Minac that will operate in the 6-MeV range and are investigating real-time filmless inspection. If successful, such advances would significantly increase Minac's applicability.

Minac's dollar benefits to utilities will be measurable in time saved and improvements in net power generation. Because a plant outage can cost $200,000–$500,000 a day, the reduced outage time made possible by Minac's portability, on-off capability, and on-line inspection capability will translate directly to dollar savings. Similarly, better diagnostic abilities will improve utilities' maintenance planning so that needed repairs can be detected early and scheduled to minimize downtime.

Finally, use of Minac can reduce personnel radiation exposure, ease compliance with mandated inspections, and produce more, higher-quality information for utility management and planning. The information EPRI has accumulated in recent utility applications will assist in determining the kind of testing requirements that will be necessary in the future. ■

This article was written by Adrienne Harris Cordova, science writer. Background information was provided by M. E. Lapides, Nuclear Power Division.



PROTECTING COPPER UNDERGROUND

Accelerated corrosion—and more frequent instances of it—is shortening the life of bare copper neutral wires on buried electric distribution cable. Some 200,000 miles of cable are at risk, mostly in suburban neighborhoods developed since the 1950s. What has changed and what is being done about it?

Beginning in the early 1960s a disconcerting phenomenon appeared on underground electric distribution systems. The copper neutral wires wound around some distribution cables were corroding away even within the first 5 years of their planned 30-year life.

The phenomenon was discovered with increasing frequency—sometimes by electric utility crews working on underground circuits, sometimes by employees of gas or telephone utilities whose lines shared the same trench.

By 1970 it was a familiar occurrence but still caused no apparent operating difficulties. It was also technically baffling because there was no precedent. Quite the opposite, in fact; buried copper wire, such as in substation grounding systems, traditionally had a problem-free life of 35 years or more.

Barriers and countermeasures

Loss of neutral wires from underground distribution cable needs context in two respects: the function of the wires and the nature of the attack on them. Neutral wires, besides being a grounding system, are usually the return leg of an electric utility distribution circuit. The insulated cable carries the conductor (the hot wire), and the neutral wires wind around its outer jacket. The configuration is called concentric neutral (CN) cable.

Because CN wires are intended to be at ground (zero electric potential), they need not be insulated from the surrounding earth. Usually, therefore, they are bare copper or lightly tin-alloy coated—more for protection from atmospheric corrosion during yard storage on spools than for protection in the ground.

Much corrosive attack underground is caused by a difference of electric potential between metals that are in contact and also connected by an electrolyte, some nonmetallic but conductive medium. When such materials are packaged and the reaction controlled, the product is a battery and its flow of useful current. When the reaction is spontaneous and uncontrolled, the result is corrosion, as the flow of current and consequent recombination of elements gradually destroy one metal.

With CN corrosion an increasing annoyance, utilities realized that some significant change was taking place in the typical underground environment. Industry response has been straightforward and productive along two paths.

The first path was early EPRI-sponsored research by General Cable Corp. (now Pirelli Cable Corp.), which identified and proved the efficacy of semiconducting thermoplastic materials for jacketing CN wires. (Fully insulated and jacketed cable was already available.) This quick fix accepted the fact of CN corrosion, bypassing attempts to explain why it was suddenly a problem. The new cable was essentially impervious to electrochemical action, and as such, it precluded CN corrosion on new underground systems—no small achievement for an industry that is burying distribution cable at the rate of about 10,000 miles (16,100 km) annually.

But it remained to understand corrosion and devise countermeasures for an unknown but large fraction of the more than 200,000 miles (322,000 km) of distribution cable already in the ground. A little of this was unrolled into place behind a cable plow, but most of it lies in excavated trenches. Some was pulled through conduit, but more is direct-buried, usually by itself but sometimes in a trench shared with gas or telephone utilities. Logic and experience assert that CN corrosion is not a certainty, so the remedy had to include finding out why and where corrosion occurs, as well as what to do about it.

This was EPRI's second research path, the work done under contract with Pacific Gas and Electric Co. (PG&E). It yielded guidelines for designing and installing cathodic protection systems, which counteract corrosion by neutralizing the corrosion process on the CN wires. The same project also produced guidelines for surveying a distribution system to learn if there is a likelihood of corrosion.

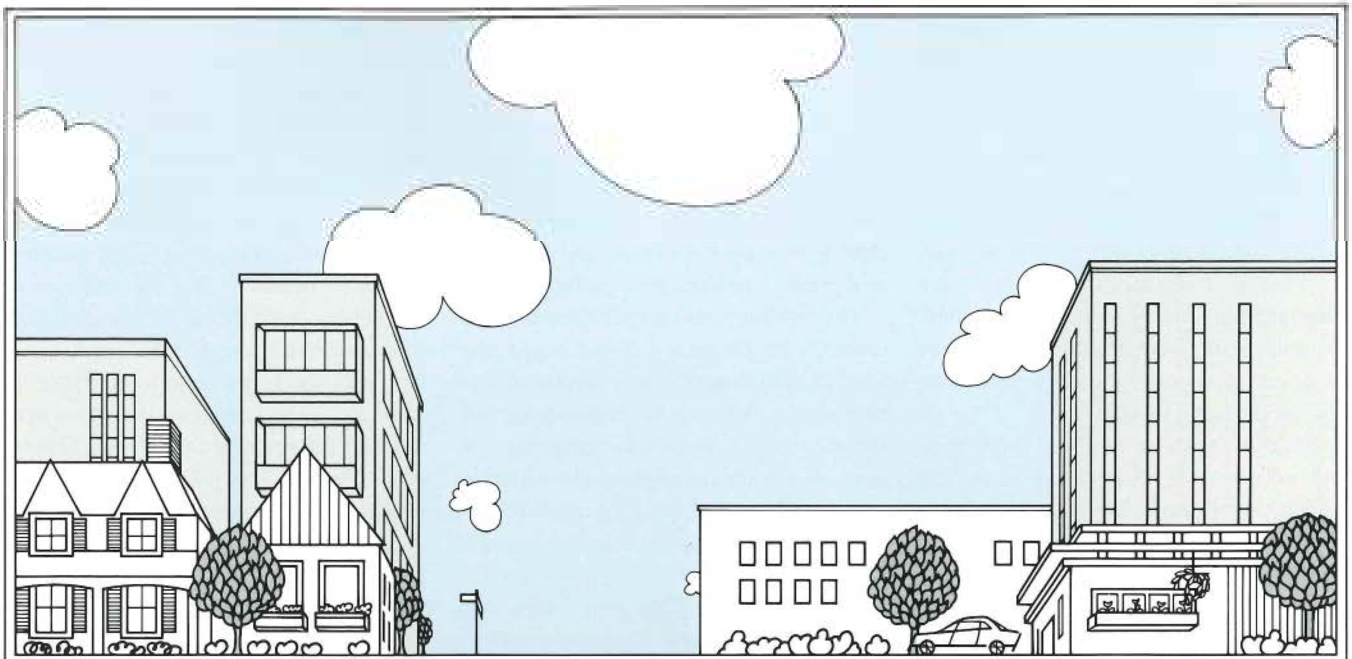
Thomas Kendrew is EPRI's project manager for CN corrosion research. He is emphatic about both research results. "The jacketed cable—either insulated or semiconducting—is viable for new construction. We recommend it highly," he says. But from his own experience with utilities, he recognizes that the jacketed cable is a mixed blessing. One reason is its cost. Another is that corrosive environments, even though more probable today, are not completely predictable. Bare CN cable and pinpointed use of cathodic protection may be more economical for some new systems. The reaction by utilities is therefore mixed, Kendrew says. "Some have standardized on jacketed cable; others still prefer cable with bare CN wires. Our more recent research supports that ability to choose."

Reasons for concern

CN wire corrosion is not a problem for cables operated at subtransmission voltage levels, generally 69 kV and above. Transmission circuit and system design considerations usually call for jacketed cables, which are essentially secure from corrosion. In addition, there is relatively little such cable compared with distribution systems, it is mostly in urban areas, and its use is not growing rapidly.

These facts stand in contrast to the situation with underground distribution, which is mainly in suburbs. Unpredictable failures in less than 5 years of a planned 30-year book life (which might reasonably be exceeded in service) could put major investments at risk. Utilities need ways to detect, evaluate, and remedy CN corrosion.

The paradox in all this is that CN wire corrosion usually does not reveal itself under normal operating conditions. If the neutral wires of one cable corrode away, the interconnected neutrals of another power cable, or the earth itself, may act as the return conductor and, of course, as ground. CN corrosion is thus economically tolerable as long as everything else is working, and it does not, of itself, appear to be a major cause of distribution



Copper is attacked because there is less iron and steel, the traditional corrosion targets, in today's underground utility en-

vironment. New research has produced guidelines for evaluating distribution systems now in place, measuring corrosion potentials, and installing cathodic protection devices to neutralize the corrosive action.

failures. All in all, the uncertainties of equipment malfunction and of safety are what make CN corrosion intolerable. Yet, until recently its occurrence would probably not be known until someone uncovered the fact in a trench.

Asked for even infrequent or unlikely operating phenomena that result from CN wire corrosion, EPRI's Kendrew explains. "Some circuit-protective devices may be telltales if they don't operate properly when there's a fault. Say a cable insulation fails. Circuit breakers and fuses at substations limit the effect. But CN corrosion may upset the timing of breaker or fuse action, permitting a larger area of outage.

"A more subtle thing," Kendrew adds, "would be the effect of unbalanced voltage. It might show up as an unusual dimming of light bulbs."

The changing cable environment

Why CN corrosion has become more prevalent was at first a mystery. But it yielded to logic and then to field and laboratory evidence of several contributing causes and specific corrosion mechanisms. These in turn fostered guidelines for their detection, measurement, and cure.

As a buried electric conductor or water conduit, copper was long thought to be very corrosion-resistant. When electric distribution systems first went underground in urban areas, empirical evidence supported this. The fact was, however, that the earth was already full of other metals, notably steel and cast iron, that are anodic (will corrode) with respect to copper. Further, electric wires were (and are) intentionally grounded for safety reasons, usually to water systems. These many iron and steel pipes also acted as anodes; that is, they would corrode instead of the copper, thus constituting cathodic protection for urban underground electrical systems. But because of the far greater mass of iron, its corrosion would be negligible.

After the late 1940s, however, suburban expansion and some seemingly minor wrinkles of esthetics and technology unexpectedly caused a gradual shift in circumstances. Suburban expansion meant widespread growth of electrical distribution systems in areas generally remote from extensive metal structures under the ground. Esthetics called for an increasing proportion of new distribution facilities to go underground instead of overhead; this has been a distinct point of design and appeal in residential developments from coast to coast. Finally, technology produced vitrified clay, cement, concrete, and (especially) plastic successors to the iron and steel earlier used for gas, water, and sewer mains and laterals.

Thus, there is relatively little, if any, strongly anodic material underground in today's suburbs, frequently none that is consistent and continuous along electric utility easements. In this new circumstance, copper has lost the luxury of being surrounded by automatic cathodic protection. It can corrode at a high rate because of elements and compounds found in soil and groundwater.

Given this new underground environment, PG&E's research for EPRI was undertaken to identify the principal and reasonably specific causes of CN corrosion. A related objective was to establish a statistically valid data base: facts and numbers that reveal and rank corrosion severity. From these funds of information were to come guidelines for utility use in the field. Some would be to assess system effects—to detect and measure instances of CN corrosion from the ground surface above. Others would be to design, install, and monitor cathodic protection systems.

Five categories

Hundreds of glass cells line the shelves and benches of PG&E's corrosion laboratory. They contain soil samples from California, Oklahoma, and North Carolina, through the cooperation of Oklahoma Gas and Electric Co. and Carolina Power & Light Co. The moist soil of each cell is fitted with electrodes, typically No. 14 copper (the customary CN wire). Rigorously monitored, these cells and their predecessors have yielded extensive data on soil resistivity, CN potentials, and CN corrosion resistance, as well as information on gradual changes in these properties.

Together with study and analysis of field experience, these data yield the conclusion that the leading cause of CN corrosion (as expressed in PG&E's report) "is use of backfills that are coarser than 'sand with silt,' as classified by ASTM [American Society for Testing and Materials]. Imported backfills are usually sandy, much coarser, and therefore more corrosive . . . than most native soils."

This observation will change standard cable installation practice. Imported sandy backfill has been favored for years. It drains freely. It acts as a uniform structural bedding material. And poured deep enough to cover a cable or conduit, it is a good cushion against the heavy clods or sharp rocks of native soil that is bulldozed in to close the trench.

James Hanck and his colleagues at the PG&E research laboratory found that some of these very properties increase the expectation of corrosion. Coarse particles mean larger voids, into which finer native soil can wash. The result can easily be differential aeration at incrementally separate points along a cable, producing differential electric potentials and localized cells of corrosion.

The simple solution (although not always correct) is to use native soil for backfill or to specify selected materials with a clay content greater than 20% for a uniform and low-void environment. Plowed-in cable has an evident advantage here, because its installation involves no backfill. Instead, the narrow, plowed furrow simply collapses against the cable, reestablishing the original environment.

The second contributor to CN corrosion is the lead-tin-alloy coating applied to many CN wires and long thought to be a corrosion inhibitor. Investigation shows that the quality of the coating, notably its thickness and uniformity, varies greatly. According to Hanck, year-long field tests show that copper and coating sometimes exchange positions within only months, the copper becoming anodic and thereafter corroding away.

"We can't really say why this is so," Hanck acknowledges. "It may start with micropores in the alloy, soil moisture there, and salts that alter the potential right at the copper surface. It doesn't happen in all soils, but it does in many." And when it runs its course, this corrosion can leave behind a hollow shell of lead-tin alloy.

Additional causes of corrosion derive from two types of electric current flowing in underground systems. One is high-density ac leakage current from the distribution cable itself, occasioned by even a minor fault, such as a small break in the insulation of a secondary (240-V) service to a house. The other is stray dc leakage current, perhaps from an electric transit system but more likely (and ironically) from the cathodic protection system of a buried pipeline.

Proximity is a major factor in these circumstances. Configuration—that is, the angular relationship of cables and pipes—is also a contributor. Utility maps are therefore a first resource for searching out sites where CN corrosion may be occurring. Depending on the output current of a pipeline protection system (up to 50 A), it can produce interference effects as far away as 1000 ft (305 m). In suburban settings, where only distribution gas and water mains are being protected, the output current is usually lower (3 A maximum) and the interference range probably no more than 50 ft (15 m).

CN wire corrosion is possible when the CN wires become the preferred path (the easiest route) for these stray currents. Corrosion occurs where the current leaves the CN wires on its way back to the source. The copper loss may be as high as 45 lb (20 kg) annually for each ampere of current discharged. If the interfering facilities are roughly parallel or at some acute angle to each other, this loss takes place along a considerable length of the cable and its CN wires. Where utilities cross at near right angles, the corrosion is concentrated, thus faster and more severe.

The fifth important cause of corrosion stems in part from utility cable installation practices, can be searched out in records, and is subject to a selective remedy. Concentrations of hydrogen sulfide, peat, cinders, and slag give rise to chemical reactions that are corrosive.

Cinder bedding, for example, has been used to augment the surface area of bare CN wires and thus provide more conductive capability in areas of high-resistivity soils. The intent is to ensure that the neutral wires are the preferred ground path. However, when wet, the cinders generate sulfuric acid, which can chemically attack the copper of the CN wires.

Guidelines for protection

Research to Develop Guidelines for Cathodic Protection of Concentric Neutral Cable is the title of the three-volume EPRI report that flowed from the PG&E work (EL-1970). The first two volumes document the detective work of identifying, classifying, measuring, and analyzing the leading causes of CN corrosion.

The third volume synthesizes the guidelines needed by utility management and engineers. Hanck comments, "Utilities can use it to develop their own standards and practices for controlling CN corrosion. Or, for utilities that don't have their own corrosion control people, it will be helpful in working with corrosion consultants."

The report details the step-by-step procedure for using a standard high-impedance multimeter and a reference electrode to measure CN potentials along a buried cable. Recorded values (mV) are some indication of the degree of corrosion protection already in effect, if any.

Other guidelines instruct engineers and field crews in measuring soil resistivity and in measuring the resistance of specific runs of CN cable. For soil of a given resistivity, the ratio of measured and calculated CN resistance values correlates directly with the degree of corrosion, even to the extent of complete CN interruption.

Soil resistivity values are a necessity for designing cathodic protection systems. The guidelines prescribe procedures for recording resistivity values transverse to the cable alignment at depths of 5 and 10 ft (1.5 and 3 m), usually at transformers and other fixtures but in any event at intervals of 300–1000 ft (91–305 m).

Cathodic protection for an underground system involves burying other metal nearby, metal that is anodic to the CN wires. The new anode amounts to a sacrifice—as current flows, it corrodes preferentially and is gradually eaten away over the years.

Two kinds of cathodic protection are available. Galvanic systems rely on the spontaneous low-level current flow from zinc or magnesium anodes encased in material selected for low resistivity and water retention to improve their efficiency. Galvanic current flows because of the inherent potential difference between the two metals, the anodes and the CN wires. The output is limited, but such systems are simple and inexpensive where soil resistivity permits their use and ac sources are not conveniently available.

Impressed-current systems rely on rectifiers that supply dc current to long-lasting anodes of graphite, high-silicon iron, platinized niobium, or platinized titanium. Again, the anodes are packed in prepared, uniform backfill. The advantage of this impressed-current system is its greater output, a necessity in highly resistive soils.

Cathodic protection systems have to produce at least 100 mA output current; outputs may range up to 250 mA without likelihood of interfering with other buried structures. The interval between systems—that is, between anode sites along the cable—is usually 300–1000 ft (91–305 m). The new guidelines explain exceptions and also detail the positioning of anodes relative to the CN cable (5–10 ft; 1.5–3 m) or to other, unconnected structures (>10 ft; 3 m).

Soil samples from many areas of three states yield data on soil resistivity, corrosion mechanisms, and corrosion rates. Coarse, sandy materials used to backfill utility trenches have been found to be more corrosive than most native soils.

System design eventually hinges on soil resistivity. For various ranges of values, the EPRI guidelines name one or more alternatives of anode material, weight, size, quantity, output current, and estimated life (ranging from 10 to nearly 80 years). Typical plan and elevation views and step-by-step installation notes are an integral part of the information presented.

After enumerating the major steps of CN corrosion surveys and cathodic protection installation, Hanck turns to page 4.17 of the EPRI report and reads the closing sentences on design and installation: "The cost of materials for one cathodic protection system was approximately $200 in 1982. A two-person crew with a boom truck and auger could install from two to six cathodic protection systems in eight hours if no CN cable excavations were necessary."

That paragraph is the only specific mention of cathodic protection costs. But for Hanck and for EPRI's Kendrew, it symbolized a capability that has been compiled and organized. Kendrew sees the report as a comprehensive tool for utility decision making. "You know your investment in an underground system," he says, "and you can estimate the cost to replace it. Now, with these guidelines there's an equally straightforward way to design cathodic protection instead. Use your own costs for labor and material, and you can decide which is the economic way to go." ■

This article was written by Ralph Whitaker. Technical background information was provided by Thomas Kendrew, Electrical Systems Division.

Demonstrating Energy-Efficient Developments

To assist in energy technology transfer, APPA's Demonstration of Energy-Efficient Developments Program provides an incentive to municipal utilities to test new products, processes, and technologies.

Over 11% of the nation's electricity is generated by local, publicly owned electric utility systems that serve about 35 million customers. In many cities these same utilities provide public services beyond electricity, including water and gas service, garbage collection, sewage treatment, and street lighting. Other public power systems go even further, into areas of city, engineering, and transportation planning. Publicly owned utilities are as diverse in size as they are in the services they offer. Los Angeles Department of Water & Power, for example, serves 1.2 million customers; Radium Light Department in Kansas, on the other hand, serves only 34 customers.

Representing this broad range of interests and needs for 1750 local, publicly owned electric utilities is the American Public Power Association (APPA), established in 1940 and headed by Alex Radin, who has been its director since 1951. APPA offers assistance to its members through seminars, conferences, and workshops; management training courses; and weekly, monthly, and annual publications. In addition, the trade association's Washington, D.C., location allows for representation of its members' views and concerns with members of Congress, the executive branch, and federal agencies.

Near-Term Needs

Performing member service–oriented functions is a typical characteristic of trade associations like APPA. Among the many programs administered by APPA is one designed to serve its members by helping them meet the electricity demands of the future: research on new technologies. APPA's energy research program was originally created in response to the 1974 oil crisis and as a consequence of the same industrywide movement that led to the establishment of EPRI—a greater recognition of the need for responsive electric power R&D.

As the growing need for near-term, energy-efficient applications became obvious within the electric utility industry, APPA responded by creating DEED, a program for the demonstration of energy-efficient developments. Begun in 1980 as an outgrowth of the original energy research program, DEED now provides an opportunity for its 130 member utilities to test and evaluate prospective energy developments designed specifically to help them provide reliable and efficient utility services.

According to Eric Leber, APPA's director of energy research and DEED, the shift in emphasis within the public power sector from performing research to the actual demonstration of energy-efficient technologies and procedures was largely due to the perceived benefits versus the perceived costs associated with research expenditures. "In today's economic climate, it is evident that every budget item submitted by utility management, or any other local government official, undergoes considerable scrutiny. There has been some trouble justifying research expenditures because they may not provide immediate, visible returns on investment. Participation in large, expensive research programs has been low because of the high cost and the lack of perceived benefits," Leber explains.

APPA's DEED program, on the other hand, emphasizes the actual field testing of developments. By providing a utility environment in which to test and evaluate products, the utility is able to gain hands-on experience, which will hopefully engender a degree of support and enthusiasm that will spill over into additional research projects. Leber adds, "The majority of DEED participants have never before played a role in supporting research, development, or demonstration. In a way, DEED is a very modest first step toward introducing utilities to R&D activities, as well as providing them with the resources, products, and experiences that work at other utilities. We have found that effective technology transfer is not from computer to computer, not from building to building, nor from mailbox to mailbox. It is from person to person."

APPA encourages its member utilities to contribute to DEED through an annual fee of 10¢ per meter served. Only 1¢ per meter is asked of APPA members who contribute to EPRI, as those contributions already provide funding support for energy R&D. The DEED program is small, but relatively effective, and member participation has grown slowly—up this year about 10–15% over last year—with total annual funding of about $250,000. The idea is to keep DEED simple and affordable in order to provide a program that will introduce processes and products of research, development, and demonstration to the broadest number of member utilities.

Through the DEED program, APPA seeks projects that involve some small degree of risk and are of wide interest and application. Those considered for grants are selected by APPA's Energy Research and Demonstration Committee. Eligible technologies run the full gamut, ranging from energy storage, load management, passive and active solar, and fluidized-bed combustion to heat pumps, heat recovery, distribution, biomass, and municipal solid waste. Much of DEED's support is based on the direct application of products conceived through or complementary to research at EPRI.

Leber

Results and Applications

Among the 35 projects that DEED has supported are two in particular in which consolidated efforts by DEED and EPRI led to successful applications. The first project demonstrated the use of a coal-derived synthetic liquid fuel, Exxon Donor Solvent (EDS), to fuel a 3.5-MW diesel engine generator. APPA, through DEED, contributed $35,000, EPRI provided $250,000, and the host utility, Easton Utilities Commission in Easton, Maryland, donated $35,000 to test the EDS fuel.

Easton Utilities Commission agreed to test the synthetic fuel for three weeks in its 16-cylinder, 360-rpm Cooper Energy Services unit. During the tests, engine performance, knock tendencies at various loads, fuel blends, and air manifold temperatures were evaluated, and the ambient air and exhaust gas were monitored. The Easton project responds primarily to the needs of smaller utilities, particularly to those hundreds of small utilities such as Easton that have diesel capacity that may be standing idle because of the dramatic rise in the price of diesel fuel and the uncertainty of adequate supplies. The project was completed on time and within the allotted budget, and thus far the tests appear to be successful. "Although the findings haven't been collated yet, I think we have shown that diesels and synfuels are compatible," comments Leber.

Another DEED-supported project—a biomass study that used local resources—involved the gasification of corncobs for electricity generation as an alternative to the traditional diesel fuel. Findings from the tests, performed by the Iowa Association of Municipal Utilities (IAMU) and cosponsored by Iowa State University and public power systems in Coon Rapids and Sanborn, Iowa, indicated that a 35-kW diesel generator could operate with a mixture of 80% low-Btu gas derived from corncobs and 20% from diesel fuel.

The potential for corncob gasification is tremendous in the 10-state corn belt, where an average of 54.5 million acres of corn is grown annually, according to an IAMU survey. The survey also demonstrated that more than 300 MW of diesel electric generating capacity is in existence in 70 Midwest communities, and these engines have the potential for conversion to the low-Btu gasification product.

The $28,000 project, which received a $14,000 DEED grant, has spurred continued investigations. The corncob project was able to continue through the preliminary design, construction, and testing phase under funding from DEED. Now through support from EPRI, that technology and related biomass gasification technologies are undergoing more thorough investigations with an eye toward wider use, higher efficiency, and greater application.

Extended Programs

In addition to these two examples of directly supported DEED projects, three programs have evolved from member needs. These programs encompass the areas of energy services planning, energy services exchange, and establishment of a public power innovations list.

The Energy Services Planning Program helps a municipal utility create a resource and a cost-efficient mix of services from heating and cooling to lighting and electricity generation. DEED assists its member utilities in selecting those technologies that seem to fit together at the right scale at the right time at the right expense. "The objective of energy services planning is to find the least-cost strategy for providing energy services to the consumer," Radin explains. "The strategy involves consideration of a broad range of possibilities, including conventional as well as unconventional resources, load management, conservation, integration of small power production facilities, and cogeneration—cutting electric usage and cost by melding two or more city services and improving the load factor."

Another related and upcoming program is the Energy Services Exchange Program, which will be cosponsored with the Western Area Power Administration. With the objective of facilitating technology transfer through an emphasis on person-to-person communications, this program will involve intense, in-depth, and on-site investigations of specifically selected technologies. The kinds of technologies to be under the initial program include innovative heat pump applications, cogeneration, load management, passive solar, biomass and local resource recovery, and community energy projects. Concentrated seminars with strictly limited attendance will be held at the utility employing the technology in question.

To further disseminate information about novel technology applications, DEED issues an annual tabulation of innovative energy-related activities in the public power sector. The 1982 Public Power Innovations List summarizes 920 activities that focus on near-term opportunities for energy technology. Annually, a panel of judges selects innovations worthy of special recognition. DEED then provides an award for outstanding and creative advances in the development or application of energy-efficient techniques or technologies. In 1981 there were six recipients of the Energy Innovator Award. For example, Palo Alto (California) Electric Utilities received the innovator award for instituting a comprehensive community solar energy and conservation program. Nashville (Tennessee) Electric Service was honored for its widespread use of infrared scanners in monitoring the performance of utility equipment and in performing energy audits.

In addition to rewarding innovation, APPA would like to discover what environments best stimulate technologic innovation. APPA, through its project on modern public power innovators, is seeking to document and report the kinds of management styles, philosophies, personalities, and working environments that encourage innovation. "The project is a primer on innovators and innovation, but it performs a number of functions. By reporting on successful techniques, utilities can benefit from one another's technical, managerial, and communications experiences," explains Leber. APPA, also through these programs, is helping its members realize that tomorrow's manager must be prepared for a life-long learning process where continuing education will become the rule rather than the exception.

Paving the Way

DEED will continue to solicit ideas on new and interesting energy-efficient concepts, many of which employ local resources. Leber elaborates, "One can expect to continue to see local, smaller-scale technologies that tend to use resources found within the neighborhood. There will be an emphasis on diversification—pursuing a somewhat broader range of activities not customarily thought of as electric utility services." Some examples of new DEED proposals include three that address the application of cable television to utility systems. One proposal examines ways of interfacing cable television with electrical distribution equipment. Finding ways to incorporate load control, remote meter reading, and computer communications is the thrust of the second proposal. The third suggests demonstrating the technical and economic aspects of meter reading via cable.

To facilitate the exchange of ideas and to encourage the testing of new theories (like those proposed in the telecommunications area), DEED publishes a quarterly newsletter called *DEED Digest*. In summarizing developments throughout the industry, the newsletter covers domestic activities within DOE, other government agencies, national laboratories, research institutions, and private companies, as well as monitoring developments abroad. (To foster better understanding of foreign initiatives in energy efficiency, DEED also recently cosponsored a European Energy Innovation Study Program.) The *Digest* is one mechanism DEED employs to promote a critical objective of the whole program: technology transfer among its members. Through technical projects, innovation support, educational initiatives, information sharing, and awards, DEED provides an eclectic approach to improving the efficiency, range, affordability, and reliability of local utility services. ■

This article was written by Ellie Hollander, Washington Office.

EPRI Joins Reactor Project

EPRI will represent the U.S. private sector in modeling experiments to test reactor safety margins.

Organizations from nine countries are sponsoring reactor accident tests at the Marviken nuclear power plant in Sweden. These tests are expected to produce more realistic and quantitative estimates of releases from postulated reactor accidents.

Many experts have concluded that the risks to the public from major reactor accidents are significantly less than now assumed in design and accident response criteria. This could mean, for example, that current estimates of evacuation zones are larger than needed. The Marviken project is part of a worldwide program addressing this issue.

Plans for the Marviken tests were finalized late last year in Norrköping, Sweden. The tests will model reactor accident conditions without using radioactive material as a preliminary step to radioactive tests, according to Walter Loewenstein, deputy director of EPRI's Nuclear Power Division. Loewenstein said that although the kind of accidents to be studied are very unlikely to occur, it is important to understand their potential consequences.

Six large-scale tests will be conducted in the $8 million Marviken project. The Swedish facility is ideal for such large-scale tests. Preparations are now under way, and work will continue into 1985.

Project participants represent government and private sector organizations from Canada, Finland, France, Italy, Japan, the Netherlands, Sweden, the United Kingdom, and the United States. The Nuclear Regulatory Commission is representing the U.S. government, and EPRI is the U.S. private sector representative. Studsvik Energiteknik Ab is responsible for conducting the program.

A project board and a technical advisory committee, each with members from all participating organizations, will direct the research effort. Loewenstein is serving on the board, and Frank Rahn, technical specialist in the Nuclear Power Division's Risk Assessment Program, is a member of the advisory committee. ■

Manufacturers Sought for New Products

EPRI holds more than 250 patents on inventions developed through Institute-funded research. Some of the patented inventions have led to new products manufactured by EPRI research contractors. The Institute is seeking additional firms interested in licensing some of the three dozen inventions expected to be ready for the commercial market over the next two years.

Getting new technology into production is the aim of EPRI's Patents and Licensing Program. Licenses are often granted to firms in return for their work on joint research programs with EPRI, although participation in EPRI research is not required in order to obtain a manufacturing license.

EPRI received its first patent royalties last year from two products—a meter for measuring electricity use of individual household appliances and an improved device for detecting capacity loss in transformers.

Other inventions, in various stages of development, range from a machine to burrow under streets and replace buried electrical cable without tearing up pavement to technology for nondestructive testing of power plant components.

Additional information about the program, as well as a complete list of licensable inventions, is available from D. E. Erickson, EPRI's manager of patents and licensing. ■

Construction Begun on Advanced Geothermal Plant

Ground was broken late last year in southern California's Imperial Valley for construction of the nation's most advanced geothermal power demonstration plant. The plant, to be built near Heber, south of El Centro, California, will demonstrate binary-cycle technology to convert hydrothermal resources (subsurface hot water) into electricity. When completed, probably in early 1985, the estimated $122 million demonstration plant will produce 45 MW on the Imperial Irrigation District's electric grid.

EPRI is funding 10% of the Heber project cost, with DOE expected to supply half the project funds. San Diego Gas & Electric Co., which will eventually become the principal owner of the facility, is contributing slightly more than 30% of the cost. Co-owners with SDG&E are expected to be the Imperial Irrigation District, the State of California, and the California Department of Water Resources.

Binary-cycle technology could unlock the medium-temperature geothermal resources heretofore considered uneconomical. The Heber demonstration is thus a vital step to expanded development of U.S. geothermal energy, according to Vasel Roberts, EPRI's geothermal program manager.

"Of the known geothermal hydrothermal resources in the United States, approximately half are in the moderate temperature range of 150–210°C [300–410°F]," said Roberts. "If developed, this represents about 10,000 MW of electricity for 30 years."

Half the nation's hydrothermal energy potential will likely remain untapped, however, until binary-cycle technology is fully demonstrated. The technology offers improved conversion and resource utilization efficiencies over conventional flashed-steam cycles—such as are in use at other geothermal reservoirs in southern California—where steam is produced by flash boiling high-temperature water from geothermal wells. The added efficiency of the binary-cycle system is necessary to economically convert heat resources in the moderate temperature range.

Preliminary engineering and design for the Heber demonstration is nearly complete, and a dual-flow axial-type turbine generator has already been ordered. ■

Computer-Aided Tower Design Program Launched

A computer program that will aid in the design and construction of advanced transmission towers and lines is under development by EPRI in a four-year, $2.67 million project of the Electrical Systems Division.

When completed, the software package will help electric utilities upgrade existing transmission lines and build new ones at costs lower than now possible. The nation's utilities plan to spend as much as $30 billion over the next two decades to install more than 100,000 miles of new high-voltage lines, according to John Dunlap, EPRI project manager. Computer-aided design could have significant impact in reducing costs.

"Utilities will benefit because they will be able to design and upgrade their existing equipment at minimum cost, while improving reliability to their customers at the same time," Dunlap adds.

Innovative techniques for designing middle-voltage (115–500 kV) three-phase single- and double-circuit transmission lines will be the focus of the work. The computer program can be used to determine the best methods for achieving electrical and structural design with respect to initial cost, total lifetime cost, electric field intensities, and right-of-way requirements.

"The most challenging aspect of the transmission line engineer's job is determining the most economical design," explains Dunlap. "So many complex factors must be considered that mental evaluation of all known combinations is virtually impossible."

Given the right information, however, the computer can evaluate all possible design combinations and point to the lowest-cost designs. "Today, this is only a concept, but tomorrow the industry will have an important tool at its disposal," says Dunlap.

EPRI and the project contractor, Power Technologies, Inc., of Schenectady, New York, will work closely with member utilities during the three phases of the project. The first phase will establish a working methodology and data base, using computer programs and engineering methods currently available.

The second phase will involve a review of current research on electrical and structural designs to determine what new information can be added to the software package. In the third phase, tests will be conducted at EPRI's Transmission Line Mechanical Research Facility in Haslet, Texas. Information gathered from the experiments will be passed along to interested utilities.

Achieving the best combination of existing designs and materials is a major objective of the project. But as Dunlap explains, "The most important result may be the collection of information leading to new, advanced overhead transmission towers and lines that will yield greater savings than today's hardware." ■

CALENDAR

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

MARCH

22–24
2d Conference on Fabric Filter Technology
Denver, Colorado
Contact: David Eskinazi (415) 855-2918

APRIL

13–15
Seminar/Workshop: Fossil-Fuel-Fired Boiler Tube Failures and Inspections
Miami, Florida
Contact: Anthony Armor (415) 855-2961

MAY

4–5
12th Semiannual ARMP Users Group Meeting
Philadelphia, Pennsylvania
Contact: Walter Eich (415) 855-2090

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

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

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

JUNE

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

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

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

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

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

Dwain Spencer, Director

BENCH–SCALE STUDIES OF COAL GASIFICATION

Large gasification reactors that convert coal to medium-Btu gas efficiently are being developed for commercial use. These gasifiers will produce fuel gas for electric power, as well as synthesis gas for methanol, ammonia, and other important chemicals. The gasification–combined-cycle (GCC) power plant in the Cool Water demonstration project (AP-2487) and the TVA coal-to-ammonia project are foremost examples; both are based on the Texaco gasifier. In addition, EPRI has evaluated the economic potential of coproducing methanol and electricity by coal gasification (AP-2212). EPRI has also studied U.S. coals in several high-pressure gasifiers that show promise for near-term applications. These gasifiers include the moving-bed reactors, such as the British Gas Corp.–Lurgi slagging gasifier (AP-1922), and the entrained-flow reactors, such as the Texaco gasifier with coal-water slurry feed (AP-2607) and the Shell gasifier with a dry, pulverized-coal feed system (AP-2844).

An atmospheric entrained gasifier suitable for utility retrofit applications was developed by Combustion Engineering, Inc. (C–E). It tested a 120-t/d process development unit in a joint effort with DOE and EPRI (RP244). The C–E process was ultimately to have been demonstrated at full scale (1500 t/d) in a retrofit project at Gulf States Utilities Co.'s Nelson plant in Lake Charles, Louisiana. Unfortunately, DOE withdrew from such large-scale developments, and both projects were canceled before reaching their objectives.

To augment large-scale test programs, EPRI has also sponsored laboratory studies and computer simulation to analyze basic phenomena. For example, during the process development unit test program, C–E's Kreisinger Development Laboratory (KDL) initiated supporting studies in a joint effort with EPRI (AP-2601). Bench-scale experiments were planned to characterize the transformation of U.S. coals and chars as they progressed through the combustor and reductor stages of C–E's process development unit gasifier. However, that project was discontinued before appropriate char samples could be provided for KDL study. The experimental test plan was therefore redirected to a more general bench-scale study of gasification reaction kinetics for several commercially important U.S. coals of different rank, based on uniformly prepared chars from those same coals.

Coal particles in general are subject to a series of phenomena as they undergo conversion in a gasification reactor.

- Release of free and bound moisture in the initial drying step
- Release and decomposition of volatile matter as the particles are heated in the devolatilization step
- Gasification of carbon remaining in the char (after devolatilization) by heat-absorbing reactions with carbon dioxide, steam, or hydrogen
- Combustion of carbon and organic matter in the heat-generating reactions, which produce the thermal energy for the above gasification reactions

In a moving-bed gasifier, residence times are long, and these phenomena occur in different zones of the bed through which coal passes as it is transformed to char and eventually to ash. In an entrained-flow gasifier

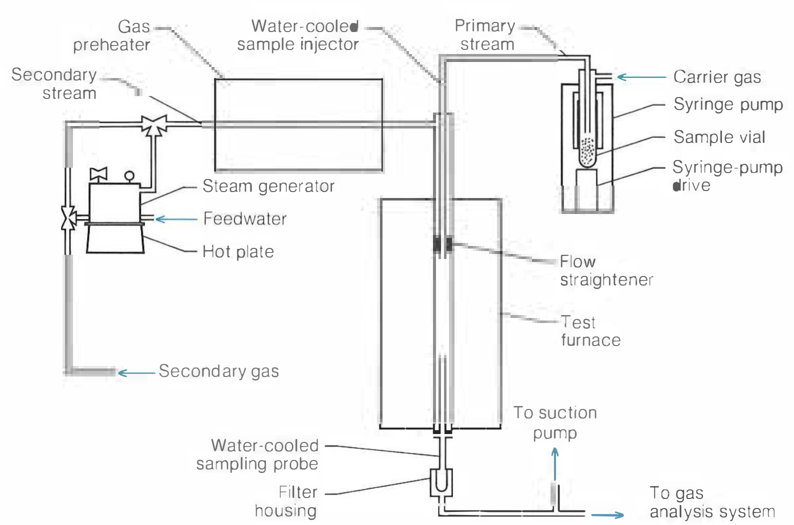


Figure 1 Solid fuel particles and carrier gas enter the reactor (furnace), where they are entrained in laminar flow with a preheated secondary gas stream serving as the preferred reacting medium. A movable exit port allows gas and solids to be sampled after a prescribed residence time.

the residence time is short (a few seconds), and the phenomena occur so rapidly that they seem simultaneous.

In the above-mentioned studies at KDL, the combustion, gasification, and devolatilization characteristics of coals and chars were determined by using a bench-scale entrained-flow reactor called a drop-tube furnace system (DTFS). Tests were conducted at atmospheric pressure with gas temperatures ranging from 1800° to 2650°F (982° to 1427°C) in the electrically heated system.

Figure 1 is a schematic of the DTFS. A small, continuous, size-graded fuel stream (0.055–0.095 g/min) is fed with a small amount of carrier gas to the hot reaction zone through a water-cooled fuel injector. A preheated secondary gas stream is fed around the primary stream. The entrained fuel particles are rapidly heated (e.g., 10^4°C/s) to prevailing gas temperatures. Reaction histories are monitored by sampling both gas and solids at points along the reaction zone, which measures 2 inches in diameter by 16 inches in length.

Leaving the reaction zone, the stream is suddenly quenched. Solids are separated from gases in a small filter, and a gas sample is sent to a precalibrated analyzer to determine concentrations of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X), and oxygen (O_2). Gasification efficiency is determined from the CO measurement; combustion or devolatilization efficiencies are based on solids conversion calculated by an ash tracer technique, assuming that ash is inert.

To analyze the coal-to-char transformation in the DTFS reactor, Advanced Fuel Research, Inc. (AFR), examined solid samples by Fourier transform infrared (FTIR) spectroscopy (AP-2602). The chars were prepared in the DTFS from four parent coals in the presence of helium at 2650°F (1427°C). The coals were a Pittsburgh No. 8 seam bituminous hvA, an Illinois 6 seam bituminous hvC, a Wyoming Wyodak seam subbituminous C, and a Texas Wilcox seam lignite A. Standard ASTM tests were used to screen the coals, including proximate, ultimate, and size analyses; higher heating value; ash composition; fusibility temperatures; and Hargrove grindability. As an important reactivity parameter, pore surface areas of coal char were specially measured by methods using N_2 and CO_2. Thermogravimetric analyses (TGA) were also made, both in air to study combustion rate and in CO_2 to assess the gasification rate, for comparison with DTFS results.

The DTFS and TGA tests consistently showed that lower-rank coal chars were more reactive than higher-rank chars and that combustion was much faster than gasification. Fuel properties, temperature, and reactant gas concentrations had great effects on both reactions. Combustion and gasification reactivities of coal char correlated well with pore surface area measurements (Table 1).

The bulk of the gasification reactivity tests were made with a CO_2 reactant medium, and only a limited number of tests were done with steam as the reactant. These limited data, primarily with Wyoming coal, indicated that the steam gasification ($C-H_2O$) reactions are more efficient than $C-CO_2$ reactions at high temperatures but less efficient at low temperatures. More research will be required to confirm such results.

From the FTIR analyses of coal char samples, it was possible to track the progress of thermal decomposition of coal in the DTFS reactor. Correlations from earlier heated-grid experiments by AFR predicted the volatile-matter release from coal in the DTFS, comparing favorably with the experimental data. AFR has also installed an FTIR system to sight across the reaction path of a similar bench-scale entrained-flow reactor for further studies featuring in situ measurement. That project (AP-2603) is expected to result in improved correlations for coal decomposition because the volatile products can be examined while in the presence of the char, and secondary reactions can be tracked more closely. Early results have shown the feasibility of the in situ FTIR analysis.

The contribution of the bench-scale studies to the overall data base on coal gasification reaction chemistry is significant. Surveys of published literature indicate that kinetic rate data, which are pertinent for analyzing gasifier development, are not readily available. In many cases reaction parameters are based on old experiments with char from unrelated sources or with specimens that were not consistently prepared.

The DTFS entrained-flow reactor has demonstrated distinct advantages for reaction studies. Much of the existing data came from TGA apparatus, which is a small batch (nonflow) reactor for determining reaction rates by overall weight loss measurement. By contrast the DTFS is a flow reactor that more nearly approximates particle conditions in large entrained gasifiers. By allowing the measurement of specific gas components, it can serve as a better means for calculating individual reaction rates, as was done in this study wherein CO was monitored to gauge the rate of the $C-CO_2$ reaction.

These experiments have great potential

Table 1
RESULTS FROM BENCH-SCALE GASIFICATION STUDIES

	Reaction Rate Coefficients by DTFS Flow Reactor Measurements		Reactivity Parameters by Thermogravimetric Analysis		
Coal Chars	Gasification With CO_2, 1447°C	Combustion With O_2, 1447°C	Gasification With CO_2, 677°C	Combustion With Air, 427°C	Pore Surface Area Measured With Nitrogen (m^2/g, dry, ash-free char)
Pittsburgh No. 8 hvA bituminous	2.4×10^{-4}	0.017	0.004	0.322	12.9
Illinois No. 6 hvC bituminous	9.5×10^{-4}	0.40	0.022	0.359	54.4
Wyoming (Wyodak) subbituminous C	5.4×10^{-3}	0.46	0.104	0.362	97.4
Texas (Wilcox) lignite A	5.7×10^{-3}	—	0.153	0.379	213.0

as the basis for a specific program of fundamental research in direct support of a commercial gasifier development. Each coal feedstock must be thoroughly evaluated in large gasifier pilot and demonstration plants, and anomalous results can cause unexpected setbacks. One such case occurred in the Koppers-Totzek atmospheric entrained gasifier when it was first installed at a coal-to-ammonia plant at Modderfontein, South Africa. The introduction of South African coals in that reactor created problems to a degree not encountered with European coals in other plants. Examples included refractory erosion, inefficient slagging, and excessive fly ash carryover. A study of coal properties ensued. It is clear that concurrent programs of supporting research may forestall such unexpected difficulties. Indeed, if such studies are undertaken early in a gasifier development program, they may actually expedite commercialization *Project Manager: George H. Quentin*

COSTS OF COAL GASIFICATION–COMBINED-CYCLE POWER PLANTS

Combustion turbine–steam turbine combined-cycle power plants could have become competitive baseload options if oil and natural gas prices had not increased between 1973 and 1980. Today, such plants can have heat rates of approximately 8000 Btu/kWh (HHV). However, they require ultraclean fuels, such as natural gas and distillate fuel oil, which are now either too expensive or unavailable to the industry as fuels for new baseload plants. An ultraclean fuel can be produced by first gasifying coal by burning it with sufficient oxygen to burn it to combustible carbon monoxide and hydrogen but insufficient to oxidize it completely to carbon dioxide and water. The resulting fuel gas can then be cleaned virtually free of particulate matter, sulfur, and fuel nitrogen compounds. The challenge is to develop an integrated coal gasification–combined-cycle power plant (IGCC) that will be competitive with a pulverized-coal-fired steam plant equipped with required environmental control systems.

Figure 2 compares the estimated costs of various sections of an IGCC power plant with comparable sections of a conventional coal-fired steam plant. The estimates for the IGCC plant were taken from continuing stud-

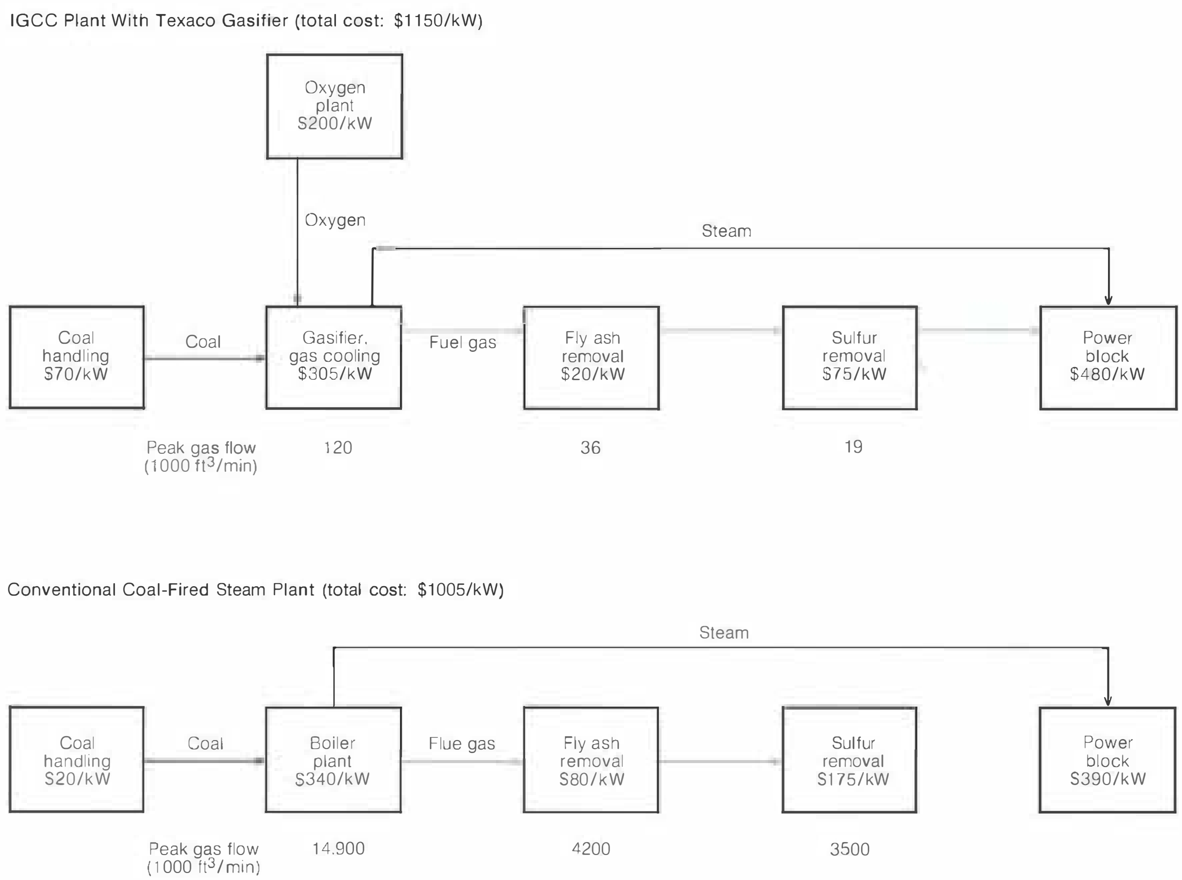


Figure 2 Comparative costs of power plants (1981 $). Total cost for the IGCC plant is $1150/kW when rated at 88°F (31°C); $1005/kW (or the same as the conventional plant) when rated at 60°F (16°C).

ies by Fluor Engineers and Constructors, Inc. (RP239), and represent EPRI's latest estimate of the cost of an IGCC plant using the Texaco coal gasification process and combustion turbines with temperatures limited to those commercially available (~2000°F, 1093°C).

The estimates for the conventional coal-fired steam plant were taken from EPRI report PE-1865, which includes cost estimates by Bechtel Power Corp. Bechtel did not prepare the sectional costs in Figure 2; they were derived by a proration of the Bechtel costs. However, they are believed to be reasonably accurate for this discussion. Bechtel's costs were originally reported in 1978 dollars. They have been escalated here to 1981 dollars using construction cost indexes.

The IGCC system enjoys an initial advantage in the gasifier, fly ash, and sulfur removal sections. This is at least partially understandable by considering the relative gas flow rates through those sections and comparable sections of the conventional plant. This advantage is then offset by the higher costs of other sections of the IGCC plant.

To determine whether an expensive oxygen production plant is feasible for preparing high-purity oxygen for coal gasification when free air can be used for this purpose, the costs of using air, oxygen-enriched air, or oxygen were studied and compared (AF-244 and AP-1624). This work showed that the cost of using oxygen in terms of both capital and product costs was essentially the same as the cost of using the other oxidants. This is fortunate because a nitrogen-free gas can be used to produce products along with electricity that are of interest to the industry, such as methanol and synthetic natural gas. The nitrogen-free gas can also be a superior fuel for integrated fuel cells, such as the molten carbonate fuel cell now under development by EPRI and others.

Most of EPRI's IGCC cost estimates include use of Texaco gasifiers. This is prudent because this gasifier will be used in the 100-MW Cool Water IGCC demonstration plant. In the past year EPRI has begun cost studies of IGCC plants equipped with other advanced gasifiers now being developed for commercial use, specifically, the British Gas Corp.–Lurgi, Shell, and Westinghouse gasifiers. Although conclusions cannot be made at the present time, it is conceivable that at least one of these gasifiers will permit IGCC capital costs to decline.

Another area of potential capital cost improvement is the increase of combustion turbine peak operating temperature (RP1319). If accomplished, this improvement can increase coal-to-busbar efficiency, which may result in an almost proportional reduction in total capital cost per kW of capacity. Reheat combustion turbine development may bring about another possible efficiency increase. A 100-MW demonstration of the reheat combustion turbine is currently under construction in Japan. This plant will not only employ a reheat combustion turbine but is also designed for combustion turbine temperatures as high as 2370°F (1300°C). The Japanese have calculated that this system will have a heat rate of 6800 Btu/kWh (HHV) when fueled with natural gas.

Capital charges represent less than half the busbar electricity costs in coal-fired systems when operated at relatively high annual capacity factors. Thus, although the capital costs of first-generation advanced IGCC plants may be slightly higher than those of conventional coal-fired plants, IGCC plants should enjoy two advantages that will help offset those higher costs. Such advantages could result in lower busbar costs even assuming conventional coal-fired plants will operate at capacity factors as high as IGCC plants. The advantages are lower coal costs and lower total operating and maintenance (O&M) costs. The lower O&M costs result principally from elimination of limestone for sulfur dioxide scrubbing and the cost of scrubber sludge disposal. To date, projections of busbar costs for the two plants operated at the same annual capacity factor indicate that the first-generation IGCC plant can produce power at about a 10% lower cost. (See, for example, AP-1624 and AP-2207.) This cost advantage might increase considerably with improved gasifiers and the advances in combustion turbine technology mentioned above.

Also of importance are advantages that could permit dispatch of IGCC plants at higher annual capacity factors than conventional coal plants.

- Potential higher annual availability
- Lower variable O&M costs because limestone purchase and sulfur dioxide scrubber sludge disposal costs eliminated
- The ability to produce more power at ambient temperatures lower than those used in EPRI cost comparison studies (88°F, 30°C)

Considerable work has been conducted to assess the potential annual availability of IGCC plants (RP1461). The conclusions to date are that these plants can attain equivalent availabilities some 10% higher than conventional coal-fired steam plants primarily because IGCC plant designers incorporate parallel and spare trains. The design philosophy in these designs is to size equipment so that all major items can be shop-fabricated, which reduces the time and expense of field fabrication.

The costs per kilowatt for the IGCC plant shown in Figure 2 are based on an ambient air temperature of 88°F (31°C). Use of this temperature yields performance estimates resulting in pessimistic or worst-case plant costs expressed in dollars per kilowatt. This design basis is used because most design studies are based on plants located in Illinois, a summer peaking area. Recent studies indicate that the net electricity output of these plants will increase appreciably at lower temperatures. For example, a plant with a 500-MW capability at 88°F could produce 550 MW at 60°F (16°C) and 600 MW at 30°F (0°C). The capability is increased because lower-temperature intake air reduces combustion turbine and oxygen plant air compressor horsepower requirements, which results in output increases. Taking the three dispatching advantages into account, the relative year-by-year capacity factors of IGCC and conventional coal plants added to expanding systems are being studied (RP2029-11).

When electricity is generated entirely from steam expansion, heat removed in the condenser is virtually all rejected to the atmosphere by vaporizing water. This continuous water loss means that plants such as conventional coal-fired steam plants consume considerable amounts of water for cooling. Condensers can be air-cooled, which eliminates cooling-water consumption, but at considerable expense. On the other hand, the cost of air cooling an IGCC plant is not considerable because the fraction of steam-cycle power to total power is low (~20–40%, depending on the gasifier). A recent study (AP-2207) indicates that an air-cooled IGCC plant might produce power at lower cost than a water-cooled conventional plant.

Fuel gas produced by coal gasification can be used to generate methanol fuel. Work is proceeding on the development of the unshifted, once-through methanol synthesis process (*EPRI Journal,* June 1982, p. 42). In this synthesis, purified gas from the gasifier is first passed through a methanol synthesis reactor, then on to a combined-cycle power plant. Studies to determine the cost of the produced methanol showed that the methanol would cost considerably less than methanol produced from coal by a nonregulated producer (AP-2212). *Project Managers: B. M. Louks, M. J. Gluckman, and A. E. Lewis*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

SO_2 CONTROL BY DRY SORBENT INJECTION

Utilities face the task of removing both fly ash and sulfur dioxide (SO_2) from the flue gas of coal-fired boilers in order to meet environmental regulations. The result is often a complex train of control equipment that requires a large capital investment. For this reason, combining SO_2 and fly ash removal processes is of considerable interest both economically and operationally. EPRI's Air Quality Control Program is evaluating the technical and economic aspects of injecting a dry sorbent for SO_2 removal into the flue gas just ahead of a fabric filter (baghouse). Fly ash and the SO_2 by-product are then both collected in the baghouse. Compounds of interest for use as dry sorbents are nahcolite (naturally occurring sodium bicarbonate, $NaHCO_3$) and trona (a naturally occurring compound consisting of sodium bicarbonate and sodium carbonate).

EPRI, Public Service Co. of Colorado, and Multi-Mineral Corp. have sponsored a full-scale demonstration of the dry sorbent injection process at the 22-MW Unit 1 of PSCC's coal-fired Cameo station near Grand Junction, Colorado (RP1682). Stearns-Roger Engineering Corp. designed the process for the Cameo unit.

In the first phase of the demonstration, pulverized nahcolite was used as the sorbent. The objectives of this phase were to determine the amount of nahcolite required to achieve an SO_2 removal level of 70% and to observe the short-term effects of the dry sorbent injection process on baghouse operation and performance.

The SO_2 removal efficiency of the dry injection system was evaluated as a function of the nahcolite feed rate and the baghouse operating parameters. The results support the findings of a previous laboratory study

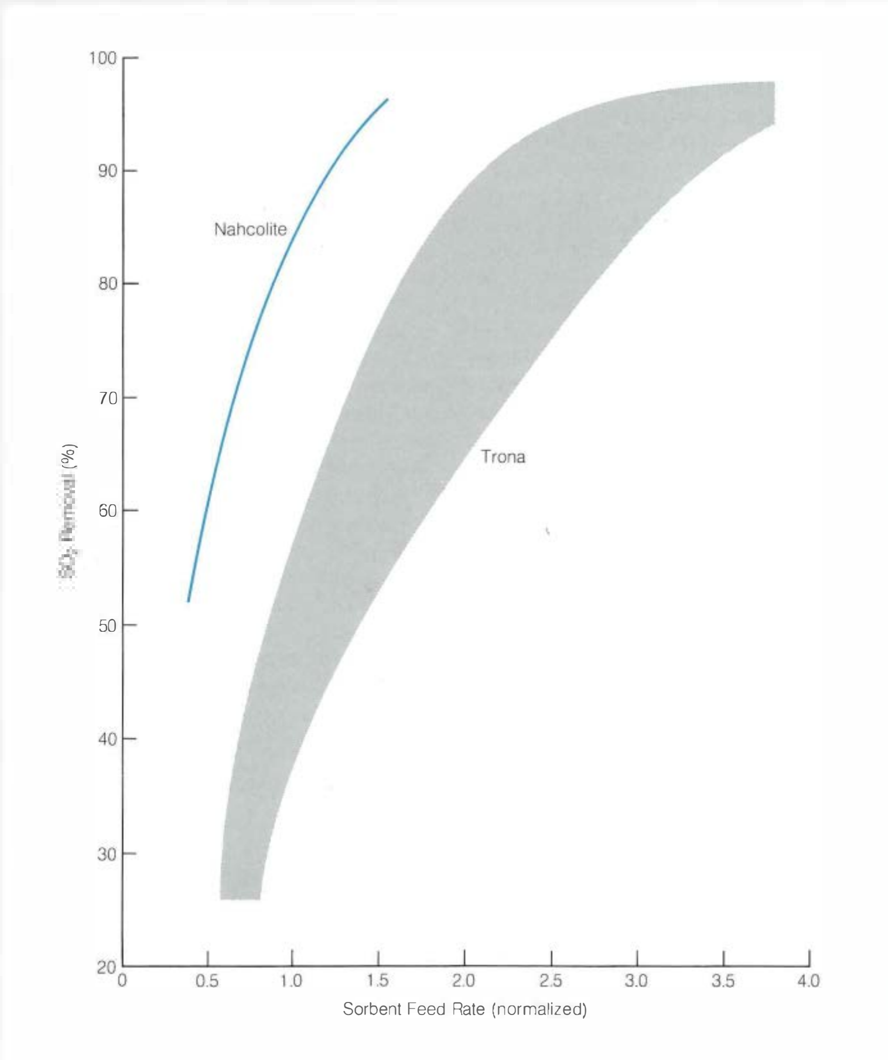
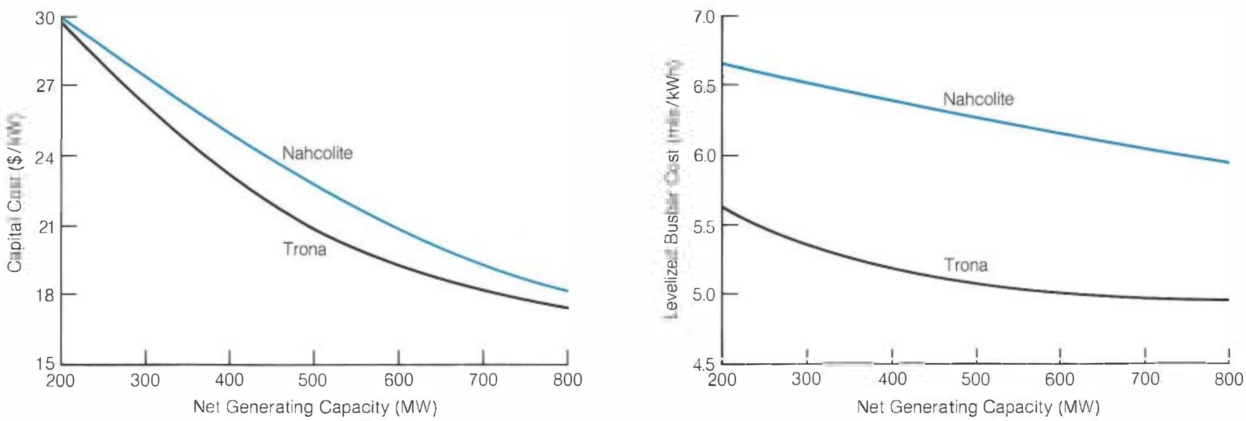


Figure 1 SO_2 removal efficiency demonstrated at Cameo for nahcolite and for trona from three different sources. The sorbent feed rate is the actual feed rate normalized to the stoichiometric feed rate. The range of results for the three types of trona indicates the importance of sorbent purity. For low-sulfur coal, regulations require 70% SO_2 removal.

Figure 2 Capital and levelized busbar costs for dry sorbent injection. The curves are based on a delivered cost of $100/t for nahcolite and $75/t for trona; coal with 0.48% sulfur and a heating value of 8020 Btu/lb; an SO_2 removal efficiency of approximately 70%; and a sorbent purity of 70% for nahcolite and 85% for trona. To estimate total costs for SO_2 and particulate emission control, the baghouse capital and levelized busbar costs—approximately $60/kW and 2.5 mills/kWh, respectively—should be added to the figures shown.



under RP982-8 (*EPRI Journal,* June 1980, p. 52). SO_2 removal was slightly more efficient in the demonstration than in the laboratory because the nahcolite injected at Cameo had been pulverized to a significantly finer particle size: 70% of the particles were smaller than 400 mesh. Finer particles have a greater reactive surface area, which (as documented in the laboratory tests) promotes greater SO_2 absorption.

In the Cameo tests, the finely pulverized nahcolite was injected upstream of the baghouse into flue gas whose temperature was 290°F (143°C). When stoichiometric amounts of the sorbent were used, an SO_2 removal level of 80% was achieved; 70% removal was achieved when approximately three-quarters of the stoichiometric amount was injected.

The impact of the dry injection process on the overall operation of the baghouse was minimal. Removing the fly ash–reacted nahcolite cake from the fabric was not significantly more difficult than the normal practice of collecting fly ash only. These findings showed that the injection process does not impose a significant pressure drop penalty.

In the second phase of the Cameo demonstration, trona was used as the dry sorbent. The results were much more encouraging than those from the laboratory investigation of trona. Figure 1 shows SO_2 removal efficiency versus the rate of sorbent injection for three very different sources of trona and also for nahcolite. The wide band representing the range of trona results indicates the importance of sorbent purity in determining the amount of material required for injection.

Simplicity is an important advantage of the dry injection process. The only steps involved at a power station are railroad unloading, bulk storage, pulverization, and pneumatic transportation of a dry product. Each of these can be performed with equipment in common use at coal-fired plants.

Following the Cameo demonstration project, EPRI initiated an economic evaluation of dry injection for both nahcolite and trona. The results indicate that low capital costs will be an attractive feature of this technology. Reagent cost and transportation will be the controlling economic factors. Figure 2 shows capital costs and levelized busbar costs for the dry injection process; the costs are presented as a function of the net power generating capacity. The results of the economic evaluation and of a comparison of the dry injection process with spray drying will be detailed in a report scheduled for publication this spring.

In the past, utilities have questioned whether sufficient supplies of sodium-based sorbents would be available to meet the demand created by utility use of this technology. To alert possible suppliers to the potential market in this area, EPRI and PSCC hosted a seminar that reported the results of the Cameo demonstration. After the seminar, several companies investigated the market and have decided to make supplies available to meet future utility needs. *Project Manager: Richard Hooper*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty Director

TRANSMISSION SUBSTATIONS

Puffer-type interrupters

There has been a continuing effort at EPRI to develop technology that will permit the design and manufacture of more-reliable and less-expensive circuit breakers of the transmission class. Part of this effort has been an investigation of arc interruption in an axial SF_6 gas flow. This work has been done in two parts by General Electric Co. (EL-284 and EL-1455). The major focus was to study the effects of nozzle and electrode geometry, which are controllable by the designer, on the interrupter performance.

As the SF_6 gas breaker technology has developed, the single-pressure, puffer-type breaker has increased in acceptance. Its single-pressure gas system with its greatly reduced number of components leads to increased reliability and lower costs. The puffer interrupter uses a relatively small volume of gas that is compressed by a piston moving with the contact during the breaker opening stroke, using energy supplied from the breaker opening mechanism. Because the pressures generated by the mechanical effort are not adequate for high-current interruption, the nozzle design must be sized so that during the high magnitude part of the current loop, the arc core will fill the nozzle throat, blocking the gas flow and thus increasing the gas pressure. The gas pressure is further raised by heat from the upstream portion of the arc and by gaseous products formed when arc action causes nozzle ablation.

The third phase of this project has been a three-year effort to apply the knowledge gained in the earlier phases to puffer-type interrupters of both the single- and double-flow designs. Here again, the primary focus was the thermal recovery problem, although limited work was done on the early phase of the dielectric recovery.

The experiments were with model-size interrupters, using double-pressure-flow systems and cold-flow calculation to optimize the designs for both single-flow and double-flow interrupters. In addition, a separate investigation was carried out on the phenomenon of blocking and deblocking of the nozzle throat, to provide the information necessary to modify the preliminary optimized designs. This was done for both single-flow and double-flow insulated nozzles. Current density at the onset of blocking and deblocking and the effects of upstream gas inflow and nozzle throat length on thermal interruption performance were determined. Measurements were made to relate the amount of ablation to current magnitude and the relative ablation of upstream, throat, and downstream areas of the nozzle.

The effects of upstream inflow geometry for double-flow nozzles were investigated by geometric screening tests on a two-pressure-flow apparatus, with the work being supported by cold-flow calculations. The cold-flow calculations provide a good indication of areas that can cause flow separation, the acceleration of flow in the vicinity of the nozzle throat, and the size of flow stagnation regions.

High-speed photography was used to show the importance of the throat region in the thermal interruption process. Studies using interferometry developed data on arc diameters and arc mantle thickness, which are important to the clogging and declogging process. Comparison of the recovery speeds of single-flow and double-flow nozzles were made to determine their relative performance.

A final report, which will assist in the design of more-effective puffer-type interrupters, will be published early in 1983. *Project Manager: N. G. Hingorani*

UNDERGROUND TRANSMISSION

Emergency ratings of cable terminations

Accurate emergency ratings for high-voltage cable terminations do not exist. Values in use were based on educated opinions and extremely limited testing. In recent years, a cable's emergency rating governed the size of new underground transmission circuits, but the emergency rating of cable terminations now governs the overall rating; hence, the need for accurate knowledge of the emergency rating of terminations. These data will allow the optimal determination of conductor size during planning and allow maximum safe cable operation during contingency situations. To explore this area of interest, a project on the emergency ratings of cable terminations was initiated with G&W Electric Specialty Co. (RP7885). The objective was the development of computer methods to accurately calculate emergency ratings of cable terminations (69 kV and above) for self-cooled and force-cooled conditions, considering all variations in cable construction and the termination environment.

Guidance was obtained from an earlier project in which the normal ampacity of a wide range of cable termination designs was studied (RP7857-1). Two computer methods were developed to calculate the normal ampacities for a range of termination designs; both methods were based on computer models of the termination structures. A matrix method includes major details of the designs, while a network method uses very simple models of the structure. The matrix method is very accurate and elaborate, but time-consuming and expensive to run; the compact network method is less accurate, but fast and easy to use, producing generally acceptable results. With these methods as a base, modifications were undertaken to include the effect of thermal inertia, the major physical parameter to be considered in transient (emergency) ratings. Thermal inertia may be roughly defined as a property that causes materials to resist instantaneous change in temperature. This temperature rise time-lag may be used to advantage—for example, allowing a very high circuit loading for a limited time, while the physical components spend time catching up in temperature to a state appropriate to the impressed conductor current.

Computer modeling of terminations was guided by data from an experimental test assembly incorporating two different 345-kV terminations, a typical capacitor-graded design and a special design for SF_6-gas-insulated entrances. Data from several previous tests made on smaller terminations, 69 kV and 161 kV, were also available (RP7857). The value of full-scale verification testing was illustrated by the discovery that even moderate changes in ambient temperature have a noticeable effect on the termination rating. Until this testing, the reverse had generally been accepted.

The matrix method was found to be too complicated to use as a universal program for emergency ratings. The network method, however, was successfully developed to accommodate the vast majority of rating situations, bringing a previously unavailable tool into play by underground system designers. The final report will be available by mid 1983. *Project Manager: John Shimshock*

Special bonding of extruded cables

In three-phase transmission systems using extruded dielectric cables, the metal sheaths of the cables must be maintained at or near ground potential (primarily for safety considerations). If this is accomplished by grounding the sheaths at two or more points along the length of the system, the sheaths will form short-circuited loops. The magnetic fields generated by the load currents flowing in the three conductors will then induce circulating currents in these short-circuited loops. The energy losses resulting from these circulating currents are substantial. Because of temperature limits, if the circulating currents are eliminated, the load rating of a system could be increased by 15–75%, depending on cable size and phase-to-phase spacing.

In short systems, these circulating currents can be minimized by single-point bonding (connecting together and grounding) the cable sheaths. In long systems, the sheaths can be sectionalized and cross-bonded (phase-to-phase transposition of successive sheath-to-sheath connections). In the latter case, it is also necessary to introduce insulating gaps (interruptions) in the extruded, semiconducting insulation shields of the cables.

One consequence of special bonding, however, is that as the circulating sheath currents decrease, the induced sheath-to-ground potentials increase. The sectionalizing lengths are selected to limit the induced 60-Hz sheath-to-ground potentials to safe levels (typically, less than 100 V under normal operating conditions). Under abnormal conditions, however, lightning, switching surges, and system faults can induce quite high voltages in the sheaths.

These transient voltages could puncture the dielectric at an interruption and precipitate a cable breakdown at that point, or they could puncture the anticorrosion polymeric jacket over the metal sheath. One way to prevent these punctures is by connecting suitable surge arresters from sheath to ground or from sheath to sheath across interruptions.

Although special bonding systems for oil-paper cables of the self-contained variety are well developed and have been in use in Europe for many years, the use of these systems on extruded dielectric cables is questionable because they are less robust. No special bonding system has yet been developed specifically for extruded dielectric cables. As a consequence, several transmission systems in the United States are currently operating with fully shorted and grounded sheaths. Although for the moment the sheath losses are tolerable, as the loading of these systems increases in the future, it will be desirable to cross-bond them.

A fully integrated system for special bonding of extruded dielectric transmission cables is the objective of RP7893. For the moment, this development is limited to 138-kV cross-linked polyethylene cables. It is intended that the components developed be suitable for all reasonable variations in cable design (types of metal sheaths and jackets) and all installation methods and environments (direct-buried and duct/manhole systems, flat and triangular configurations, wet and dry environments).

The prime contractor on this project is McGraw-Edison Co., which is responsible for analyzing the various voltage and current transients to be expected in various systems; establishing the functional requirements of all the components in the system; developing surge arresters based on metal oxide varistor (MOV) technology; and designing the various bonding systems. Pirelli Cable Corp., under subcontract to McGraw-Edison, is responsible for developing the dielectric interruptions in the cables' semiconducting shields and metal sheaths and for developing the low-impedance interconnecting cables.

Preliminary findings indicate that the most severe voltage transient imposed on the dielectric of the shield interruption occurs at the initial moments of a cable breakdown. The energy to be dissipated by the MOV blocks for these rapid transients, however, is well within their ratings. The most promising design of the shield interruption appears to be one molded directly onto the cable. The interruptions are independent of the cable joints to permit utilities to use whatever joint design they prefer. *Project Manager: F. G. Garcia*

OVERHEAD TRANSMISSION

Ac voltage effect assessment

The effects of overhead transmission lines on humans continue to be of great interest. These effects can be roughly divided into two categories: long-term and short-term biological effects. Although the Energy Analysis and Environment Division has several projects addressing long-term biological effects, this report concerns only short-term effects.

When considering short-term electric field effects, most people immediately think of shocks, but there are other effects that may occur. For example, computer chips can be damaged by static voltage. Is shielding for microelectronics needed for their application near power lines? Everyone is familiar with shocks in daily life. Some can be felt, such as a carpet shock; others cannot. Although shocks felt near a power line seem to take on a special significance, they should not; essentially, they are the same as those experienced in everyday life.

The first major step to provide information on short-term field effects was the publication of EL-802. In this project, techniques were developed to calculate the magnitude of voltages on conducting objects near a power line (Figure 1). The response of humans to various levels of shock has been

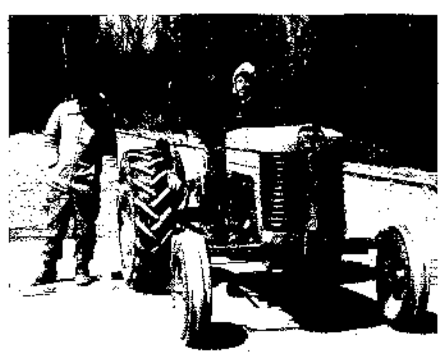


Figure 1 Researchers measure voltage. When a vehicle, such as a farm tractor, passes under a transmission line, a charge can be induced on the frame. This charge would normally be bled off during operation of the tractor, but in a worst-case situation, the tractor can be regarded as resting on rubber mats (fully insulated).

determined in other studies. An effect is caused by a series of connected events—like links in a chain. At one end of the chain are the induced voltages; at the other, the reaction of the person. In the middle, a variety of possible conditions may be present. What is needed is a probabilistic assessment of each link in the chain of events that connects the voltage to the person.

Risk assessments are used for a variety of purposes. New drugs undergo a risk assessment before they are released to the public. People may make a quick risk assessment before a trip by airplane. The same techniques need to be applied to electric field effects because they, too, are a result of a series of variable conditions. Knowing the probabilities of occurrence of each event leading to an effect and combining them properly will produce a realistic effect assessment. A scenario composed of a series of worst-case situations will not.

To assist the utility engineer in making a probabilistic assessment, a project is now under way at the High-Voltage Transmission Line Facility (HVTLF) in Lenox, Massachusetts, where a framework will be developed for effect assessment that evaluates the entire exposure process (RP1591-1). In this project, electric field effects of interest will be identified, a framework for effect assessment will be developed, and a sample case will be analyzed within this framework. The goal of this project is to develop a method by which any ac field effect can be assessed. If electric utilities, regulators, and the public agree that this is an acceptable effect assessment method, a major milestone will have been accomplished. *Project Manager: John Dunlap*

POWER SYSTEM PLANNING AND OPERATIONS

Optimal power flow research

Optimal operation of a power system implies minimum cost of operation; at the same time, security, reliability, and constraints on equipment operation must be considered. Because of the size and complexity of today's power systems, computer programs help system dispatchers and planning engineers arrive at optimal operating conditions. Not only real power flow but also reactive power flow and bus voltages must be scheduled if the power system is to be operated as efficiently as possible. And now, rising fuel costs, questionable fuel supplies, decreasing system reserves, and limited operating budgets have created conditions that must be simulated more accurately for proper resolution. The speed and accuracy of advanced computers can be enlisted for this. However, it is necessary to consolidate the requirements of the application before a computer can be used effectively. Three areas of application exist.

- System planning. The same power system components are available for optimization and must be utilized, but the computer solution time is not critical.
- System operations. The same equipment is available, but the computer solution time is critical.
- Resource planning. Additional power system resources are available (new or existing) and may be added or retired over time, but the solution time is, again, not critical.

The intent of the first phase of this research project on optimal power flow is to develop a set of recommendations for large-scale, optimization-type computer programs (RP1724). A questionnaire has provided application and user requirements, and a continuing literature search is under way to determine the best solutions for each application. Utility interviews are being used to supplement the questionnaire and literature search. The larger issues to be addressed here are the potential applications and the solution procedures. This first phase is also intended to identify both planning and operation requirements (including real time) for the optimal power flow. A handbook on optimization for power system planning and operations will be published.

Energy Systems Computer Applications, Inc., is the contractor for the first phase of the project, which is scheduled for completion in late 1983. The next goal is to develop large-system production-grade programs during the second phase for distribution by EPRI's Electric Power Software Center. *Project Manager: John W. Lamont*

Stability analysis of power systems by probabilistic methods

Power system stability analysis is presently performed by using deterministic models and analysis. Neither the existing algorithms nor the analysis is able to reflect the uncertainty of an event's occurrence, the system conditions under which the event may occur, or the system stability or instability that results. Further, such deterministic evaluation does not provide a measure of the cost of facilities to survive a given disturbance versus the probability of the occurrence. A probabilistic capability would be a major aid in planning and operating bulk power systems.

A 14-month project was initiated to develop a probabilistic (versus deterministic) approach to power system stability analysis. The goal was to seek a fast screening tool for stability analysis, taking into account the probability of disturbance type and location.

Originally, it was intended to construct a totally probabilistic model in which all dimensions of the problem were assumed to be probabilistic. However, when the contractor, Arizona State University, started the problem formulation, a totally probabilistic model appeared to be both mathematically intractable and computationally unwieldy. Hence, EPRI and the contractor agreed to start with a simpler problem formulation—using a deterministic model for certain dimensions of the problem, such as the initial load condition and initial network topology. Probabilistic models were then developed for other dimensions of the problem, such as the type, location, and sequence of system disturbances; the statistical distribution of disturbances; protection system configurations; and the statistical distribution of stability. In addition, the contractor developed solution methods for computing the relative stability of power systems.

The results published in the final report (EL-2797) are not intended to be immediately applicable by themselves; rather, they complement other EPRI research and identify areas where further research and development can prove most beneficial. For example, the probability models and the rudimentary computer code developed in this project for the analysis of system stability should serve as a basis for undertaking the comprehensive development and testing of these analytic methods (or stability analyses). Also, the findings lend support to further development and testing of a direct assessment of stability of a power system in a companion project on transient stability margin as a tool for dynamic security assessment (RP1355-3). *Project Manager: Neal J. Balu*

Modal analysis of power systems

Power system engineers have long sought methods for the evaluation and control of low-frequency electromechanical oscillation modes of power systems. Such methods should have the characteristics of computation speed, efficiency, and accuracy. Existing time-domain and modal analyses fall short of these capabilities.

For example, the traditional time-domain solution methods have limited ability to simulate stability in specific systems under specific disturbances. They are not amenable to extensive large-scale system analysis because of their computation requirements.

And modal analysis methods developed by other researchers construct a reduced order model for the external system (external to the study system) for use with the study system for transient stability analysis. These methods are not suitable for dynamic stability analysis because they do not reflect the effects of the reduced system on certain electromechanical modes of the study system.

The selective modal analysis method (SMA) in this project developed a technique for identifying the system parameters that are significant in producing the critical oscillation modes and developed methods for constructing reduced-size systems that accurately reflect the effects of other parts of the system on the critical oscillation modes (RP1764-8).

The major contribution of this project was the development of a method for evaluating the dynamic stability of power systems by reducing the initial system model to a smaller one that preserves the swing modes of interest. The applicability of the method is illustrated by the computation results on a 39-bus test system. The underlying philosophy of this method is the frequency-domain analysis of power systems, as opposed to a time-domain analysis used for transient stability simulations. Comprehensive computation development and testing of the SMA method are required, however, before it can be applied as a practical tool for power system planning and operations.

This project is one of a series of eight advanced concepts projects under RP1764. The results published in the final report (EL-2830) are not intended to be immediately applicable by themselves; rather they complement other EPRI research and form a basis for further development. *Project Manager: Neal J. Balu*

Optimization of VAR sources in system planning

A project to develop advanced optimization methods for reactive power (VAR) allocation in large-scale utility systems is progressing according to schedule (RP2109). The background of this 20-month project (started in November 1981 with Scientific Systems, Inc.) was described in the July/August 1982 issue of the *EPRI Journal*, p. 45.

The project activities are organized into five major tasks.

- Task 1: a review of the characteristics of a wide range of VAR sources and control equipment in use by the utility and the criteria for their selection, use, and coordination for voltage and reactive power control
- Task 2: problem formulation, modeling, and determination of data availability and users' needs for evaluating system reactive power requirements for both system planning and operations
- Task 3: review of the state-of-the-art optimization techniques to determine their applicability for VAR allocation in large-scale power systems
- Task 4: development of advanced optimization methods and a prototype computer program for determining the size and location of reactive power sources
- Task 5: testing and validation of the methods and the prototype program by analyzing the performance of representative large-scale utility systems (up to 1500-bus systems).

The contractor has completed Tasks 1, 2, and 3. The most significant accomplishment in this project thus far is the development of a decoupled optimal load flow program suitable for large-scale system analysis. The program has been successfully tested for active power optimization, and the testing of reactive power optimization is in progress. The project is scheduled for completion by August 1983. *Project Manager: Neal J. Balu*

Fast voltage estimation

Regulation of voltage and prevention of voltage collapse in bulk power systems are serious concerns today. Currently, there are locations where generators are not dispatched at lowest overall cost because of concerns for maintaining voltage during optimal generator dispatch. The extra costs of suboptimal generation dispatch can be saved and the risk of low (or high) voltage problems reduced if the effect of contingencies or shifts in generation pattern or power interchange on bus voltages can be predicted. The large number of scenarios to study and the short reaction time allotted planners and operators require that these voltage predictions be done quickly.

Years ago, analysis of thermal overload problems associated with MW flow on transmission lines and other equipment could be avoided only by using cumbersome time-consuming techniques. Now, methods are commonly used to quickly estimate the thermal limits of power systems. Thermal factors (often called DFAX for distribution factors) are easily calculated with linear methods. In contrast, rapid voltage limit analysis is not available because linear analysis methods cannot be used. Fast, efficient, and sufficiently accurate voltage estimation methods, corresponding loosely to a voltage DFAX technique, have been slow in developing.

A project is under way to provide utility operators and planners with one or more improved computer tools for quickly calculating voltages in power systems (RP2148). Power research results suggest that new approaches are available that may work in one-tenth the time of the fastest methods used today. In Phase 1 of this two-phase project, these new approaches will be developed and tested for speed, accuracy, and compatibility with other system analysis programs (e.g., security analysis, optimal power flow, transmission reliability evaluation, and VAR planning). Prototype computer programs used for development and testing will be distributed on an as-is basis at project conclusion early in 1984. If Phase 1 is successful, Phase 2 will focus on developing a production-grade program. Systems Engineering for Power, Inc., is the Phase 1 contractor. *Project Manager: J. V. Mitsche*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

LEGIONELLA STUDY

An outbreak of a disease during a 1976 American Legion convention in Philadelphia resulted in the identification of pathogenic bacteria (Legionella pneumophila), *commonly referred to as Legionnaires' disease bacteria (LDB). Subsequent research has identified LDB as widely existing bacteria that do not usually affect human health. However, under certain conditions, which are still unknown, these bacteria can become virulent and cause a pneumonialike infection. Because LDB have been found in air conditioning cooling towers and evaporation condensers and because the utility industry operates the world's largest cooling towers, utilities considered it important to determine the existence of LDB in the power plant environment. After consulting with the Centers for Disease Control in Atlanta, Georgia, and several utilities, EPRI contracted with Oak Ridge National Laboratory to study whether the power plant environment affects LDB development, abundance, and infectivity. Results so far show that these bacteria exist in power plant cooling waters, but their numbers fall below the concentrations generally accepted as threatening to public health.*

The LDB project was designed in two phases. Phase 1, which has now been completed, surveyed a number of different types of power plants to determine if cooling system design (either open or closed cycle) affected the occurrence of LDB. Additional objectives were to identify whether certain characteristics of LDB-containing water were associated with season of the year and/or water quality.

During Phase 1, water samples were collected four times during the year at nine power plants that covered a range of geographic locations and plant operating conditions. Four of the plants are in the northern Midwest, four in the Southeast, and one in the East. Six of the plants are coal-fired and three are nuclear. Four of the plants employ once-through cooling; two are variable-mode plants using mechanical-draft or once-through cooling, depending on season of the year; and three of the plants employ closed-cycle cooling (one natural-draft and two mechanical-draft). Three samples were collected at each plant's intake and discharge areas, and single samples were collected from or near the inlet and outlet condenser water boxes. Sampling began in March 1981 and was completed in February 1982.

Bacteria were isolated from the water samples, which themselves were subject to extensive physicochemical analysis. At most plants the water analyses and preprocessing steps for LDB analyses were conducted onsite in a mobile laboratory. Where use of the mobile laboratory was not feasible, samples were sent by air to the laboratory for processing. Water samples were tested, using standard techniques to measure temperature, pH, conductivity, alkalinity, and concentrations of dissolved oxygen, phosphate, nitrate, ammonia, organic carbon, inorganic carbon, and total carbon. Bacteria were characterized on the basis of concentration, viability, and virulence.

For LDB analyses an 8-liter water sample was spiked with a tetrazolium dye (for viability estimates), then concentrated 500 times by continuous centrifugation. LDB density, as well as strain or serogroup identification, was determined by the direct fluorescence antibody (DFA) technique on 0.01-ml aliquots of the concentrated sample. This technique attaches a fluorescent tag to each bacterium, which then can be readily seen in the microscope. A polyvalent antiserum specific for the four major strains or serogroups of *Legionella pneumophila* was supplied by the Centers for Disease Control. LDB viability was determined by electron transport system activity, using combined epifluorescence and bright field microscopy. The pro-

Table 1
VIABILITY OF LDB IN WATER SAMPLES
(mean percent)

	Open-Cycle Site		Closed-Cycle Site	
	Ambient	Plant-Exposed	Ambient	Plant-Exposed
Spring	32	39	14	26
Summer	24	22	8	5
Fall	21	24	15	17
Winter	30	29	36	31

portion of bacteria showing evidence of uptake of the tetrazolium dye gave an estimate of the proportion of viable organisms. Infectivity was examined in selected water samples, using guinea pigs. (This is an accepted isolation technique for use with clinical specimens, but it is not possible to relate the results directly to humans.) The animals were injected in the abdomen with 2–3 ml of the concentrated sample. For the next 10 days animals were observed for either a body temperature rise of $\geq 0.6°C$ for two consecutive days or a smaller temperature rise coincident with overt signs of illness. If the animals showed these signs of infection, they were examined by dissection. *Legionella* isolates that appeared in cultures of guinea pig tissues were identified by species and/or serotype, using the DFA technique. Isolation of LDB was considered presumptive evidence that LDB had caused the infection.

LDB were detected in all but five of the water samples, including intake as well as plant-affected (postcondenser or discharge) waters. LDB are ubiquitous and appear to be part of the normal complement of organisms found in natural aquatic environments. The DFA's lower limit for detecting LDB by using the above procedures is 10^3 organisms per liter. Most water samples contained LDB in the range of 10^4 to 10^6 organisms per liter. The currently accepted level for instituting control measures for public health protection in building air conditioning systems is LDB densities of greater than 10^8 organisms per liter. Therefore, LDB concentrations in power plant systems do not appear to exceed the level for which control would be necessary. It is generally presumed that these concentrations present little or no health hazard.

Effects of power plant operation on water sample LDB variables appear to depend on the characteristic (e.g., density, infectivity) chosen for comparison, type of cooling system, and season of the year. Conclusions based on preliminary analysis can be summarized as follows.

- Viability of LDB in water samples was variable.
- Viability tended to be lower in summer and fall but was not different in ambient and plant-affected water samples (Table 1).
- In spring, LDB density was lower in plant-affected waters at closed-cycle plants, but in other seasons and at all open-cycle plants, densities were equivalent in ambient and plant-affected waters. Density is expressed in Table 2 as the log of the number of cells per milliliter (e.g., $2.6 = 4 \times 10^5$ LDB per liter).
- Infectious samples were found in all seasons in the plant-affected waters, but only in summer, fall, and winter in ambient waters.
- A higher proportion of infectious samples was found in plant-affected waters of closed-cycle plants than in ambient waters; no such differences were found at open-cycle plants (Table 3).
- Sample infectivity could not be related to LDB density, viability, or combinations of the two variables.
- Several methods of statistical analysis indicated a number of physicochemical variables that appear related to LDB density and infectivity, but cause-effect relationships cannot be established from these data.

A new species of LDB (tentatively named *Legionella oakridgensis*) was identified during this study. The clinical importance of this species is uncertain, but it was the third most prevalent *Legionella* organism isolated from samples that caused infection in the guinea pigs.

Phase 2, which was initiated in the summer of 1982, is directed at determining causal relationships between selected physical, chemical, and biotic water quality parameters and LDB density and infectivity. Phase 2 incorporates laboratory and field work. The former will be used to determine causal relationships between physicochemical water quality parameters and LDB profile variables (e.g., density, infectivity). Causality will be determined by taking cultures of known noninfectious concentrations at different levels of a single water quality parameter (e.g., temperature) and then testing for illness in guinea pigs. (Infectivity is a measure of relative potency—in this case, of the ability of *Legionella* of a specific density to produce infection in guinea pigs.)

Field studies have three objectives. Noninfectious LDB concentrations will be placed in 50-ml chambers fitted with 0.22-μm membrane filters and placed in cooling towers.

Table 2
DENSITY OF LDB IN WATER SAMPLES
(cells/ml)

	Open-Cycle Site		Closed-Cycle Site	
	Ambient	Plant-Exposed	Ambient	Plant-Exposed
Spring	1.7	1.6	3.9	2.9
Summer	2.1	2.1	2.5	1.8
Fall	1.6	1.5	1.7	1.5
Winter	2.6	2.7	2.6	2.6

Table 3
INFECTIVITY OF LDB IN WATER SAMPLES
(mean percent)

	Open-Cycle Site		Closed-Cycle Site	
	Ambient	Plant-Exposed	Ambient	Plant-Exposed
Spring	0	0	0	59
Summer	25	27	33	71
Fall	50	22	40	67
Winter	17	50	100	44

Comparison of water quality associated with noninfectious to infectious conversion and water quality not associated with such conversion will be used to identify parameters for further laboratory examination. Additional chamber studies will be used to validate laboratory results. Field studies will also try to determine the interaction of LDB with algal populations, particularly when high densities of presumed infectious LDB are found. Phase 2 studies will be completed late in 1983.

An additional series of studies, to be initiated in the summer of 1983, will focus on plant downtime, when workers clean condensers and/or cooling towers. These studies will compare LDB profile variables (e.g., density, infectivity) from aerosol, sludge, and water samples taken during downtime with those taken during normal operation. The studies are scheduled to end in the spring of 1985 and will complete ecological analysis of the relationships between LDB and power plant operation. *Project Manager: J. S. Mattice*

UTILITY INVESTMENT ALLOCATION METHODS

The utility industry is the most capital-intensive industry in the United States. Raising new capital is very expensive, and utilities are concerned about the capital markets' reception to their financing needs. Utility planners are therefore developing minimum-investment plans that, in addition to curtailing capital requirements, keep business risks at an acceptable level. In response to these changes in the utilities' planning needs, EPRI's Energy Resources Program is developing a package of planning tools that will help utility managers to analyze trade-offs among investment allocations—to allocate scarce resources more carefully and, in particular, to develop ways to conserve capital. Analytic tools must combine conventional, technology-oriented electricity planning methodologies with investment risk analysis methodologies. Wherever possible, particularly in the initial stages of this EPRI research, existing computer models will be used or enhanced, including models now available in the utility industry and models adapted from other industries with similar business planning problems. As experience with the analytic requirements of the investment allocation problem grows and the products of research materialize, it may prove necessary to develop entirely new methodologies—advanced planning methods—for the utility industry. The objective in developing these methodologies will be to construct and demonstrate new generic planning tools and to transfer them to individual utilities for their own analyses.

Many investment options are available to utility managers, such as capacity expansion, existing plant productivity improvement, power purchases, cogeneration, renewable resources, interties, and load management. Moreover, each investment has unique risks associated with it that must be balanced against other investments by equivalence measures determined by the individual utility. For example, utility decision makers must decide how to allocate limited amounts of capital between capacity expansion and end-use investments, such as load management. Investment risks in capacity expansion include long construction lead times, cost escalation, and an uncertain regulatory environment. The end-use investments are also risky because of such factors as uncertain customer behavior, technology reliability, and market penetration. The objective of capital resource allocation decisions is to choose a combination of investments that minimizes the required capital and keeps risk to the utility and its customers at an acceptable level.

A single analysis tool that integrates all capital allocations goes beyond the present state of the art in model development. Consequently, EPRI's present research is divided into topics that study the trade-offs between investment options two at a time, as well as the methods for analyzing these trade-offs.

The research examines trade-offs between investments in generation capacity and end-use technologies, trade-offs between investments in generation capacity additions and existing plant enhancements, and business planning methods used outside the electric utility industry that may be adaptable to utility use. An additional small research effort tests existing planning models by applying them to the industry's new planning problems (RP1483).

Conventional generation capacity and end-use technologies

The research goal in this area is to develop a tool or system of tools that can confirm analytically the combination of end-use and capacity investments that minimizes a utility's capital requirements at an acceptable risk.

A current research project with General Electric Co. (RP1998) is assessing the different opportunities for utilities to become involved in end-use technologies, possible mechanisms and levels of investment, and a method for computing the expected cost-benefit of specific alternatives. The project was initiated in November 1981 and a briefing document describing existing utility involvement in end-use technologies and possible new areas and levels was prepared. This project is developing a practical analytic methodology that uses return on investment and risk to evaluate the utility business potential for end-use involvement.

The overall methodology flow can be illustrated as beginning at the base of a pyramid with an idea of a specific potential end-use technology or application (Figure 1). A series of analyses is made that focuses on a business assessment, identifying the strengths, weaknesses, and interrelationships of the utility, its competition, and its business environment. Following this business assessment, the strategy development stage of the methodology is entered, wherein the requirements and resources needed for success are identified. Finally, the measurement stage is entered, in which the resource requirements and potential end-use involvement outcome benefits are compared with such utility corporate objectives as return on investment, financing requirements, and business risk.

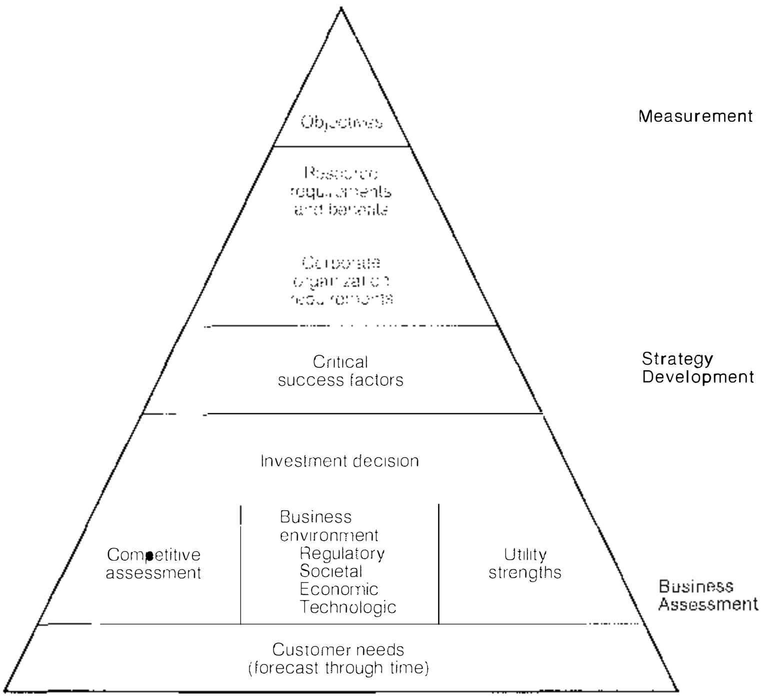
This methodology flow process is a procedure for the strategic planning of only one energy end-use application. In practice there may be many energy end-use candidates, each with different resource requirements and potential outcome benefits. All these energy end-use candidates compete with other investment alternatives for the limited resources available to the utility. Not all candidates will receive an allocation of the utility's resources—poor prospects will be pruned from consideration and good prospects will be nurtured. To facilitate and decouple the integration into smaller, more manageable units, the utility will set corporate goals for each unit, such as required return on investment, level of business risk, financing, and management attention. These utility goals then serve as a screen by which to evaluate candidate opportunities within the business unit.

A key step in the methodology is the investment decision analysis, which permits the utility end-use planner to construct all the viable options and begin to assess what is required in end-use energy business. A major research project to develop a modeling system for the end-use versus generation capacity decision was initiated recently with General Electric (RP1614).

Trade-offs between investments

The objective of this portion of the research is to develop, test, and transfer to utilities an integrated tool suitable for determining com-

Figure 1 This pyramid summarizes the steps in the analysis of a particular investment opportunity. The bottom section, business assessment, is the first step, and the analysis moves up the pyramid. Each upward progression uses the information below it in an integrated, consistent way. The concept is based on the strategic planning methodology originally developed by General Electric Co. in 1971.



binations of existing and new plants that minimize a utility's capital requirements under acceptable risk. From a decision-making perspective, allocating utility resources to new construction, existing plants, or load management presents similar challenges. Each has its own set of options, associated costs, estimated marginal benefits, imperfectly known parameters, and uncertain outcomes. Each must be evaluated on a cost-benefit basis within the set of options and against the alternative opportunities. Many utility planners sense that no single capacity option is optimal and that given the uncertainties involved, it is wise to hedge by pursuing a mix of strategies. Logically consistent ways of analyzing the value of this capacity diversity are needed.

A project with Temple, Barker & Sloane, Inc. (RP2074) focuses on investment decisions involving all types and vintages of existing plants (e.g., reconditioning, increasing maintenance, mothballing, major rebuilding in place, uprating, and technology changes). Investment decisions concerning existing plants will be integrated with new-plant decisions; major uncertainties in construction cost escalation, regulatory treatment, load growth, and fuel prices will be included in the analysis.

Planning methods used outside the electric utility industry

The goal of another project (RP1634) is to assess planning methods available from and/or being used by other industries and then to adapt and transfer appropriate methods to utilities.

Businesses outside the electric utility industry have developed many different types of planning methods and tools to support management decision making in an era of high inflation and a rapidly changing and uncertain environment. Some of these methods appear trivial and obvious, but some have made, or are capable of making, substantive contributions to the planning process. There is a considerable amount of information available about these methods and their application to real-world problems. The research will gather this information and determine which, if any, of the methods have desirable characteristics in terms of utility planning needs. Follow-on work will adapt such planning methods to individual utility users.

A preliminary survey of available planning methods has been completed, documenting methods that appear useful to the utility industry and evaluating the performance of these methods in private industry applications (TPS81-813 with André Perold). Some examples of methods are risk analysis, risk matrices, experience curves, portfolio analysis, capital asset pricing, and external environment scanning techniques.

A major research project to evaluate and adapt selected planning methods to utility use has recently been initiated with Booz, Allen & Hamilton, Inc. (RP1634).

Testing existing planning models

The research objective in this area is to test and evaluate utility planning models by applying them to emerging issues. Because new utility models are being developed and existing models are constantly being improved, there is a continuous need for up-to-date information on the capabilities of models of interest to the utility industry. In addition, as new issues or problems arise, there is a need to know if existing models have the capability of supporting analyses of these new issues. For those issues and models that are associated with utility investment decision making, research is being conducted to evaluate the capability of these models and to help understand how to structure an analysis of the issues.

The ability of a utility strategic model based on system dynamics to capture the effect of feedback on the end-use versus new capacity decision has been tested for price, regulatory, and capital market feedbacks by Pugh-Roberts Associates (RP1483). Incorporating these feedback effects materially changes the results of the analyses. In addition, the model is being applied to the plant cancellation/deferral decision. Finally, the model's capability to handle financial performance fixes (e.g., issuing stock only when market-to-book ratios are at least unity), different capitalization ratios, and changes in the ratio of fixed costs to operating costs has been tested. The ability of this model to capture the behavior of key players in the external environment has provided new insights into the efficacy of alternative investment strategies. *Project Manager: Dominic Geraghty*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

LEAD–ACID BATTERIES FOR EVs

The propulsion battery is the single most critical component of the electric vehicle (EV); it not only limits vehicle performance and range but it also dominates initial and operating costs. Current state-of-the-art EVs are powered by batteries that were designed for golf carts. Under the demanding EV driving missions, the lives of these batteries have been limited to approximately 200 cycles, resulting in unacceptably high vehicle operating costs. Recent developments in lead-acid battery technology offer the promise of significant improvement in performance and cycle life. If successfully implemented in practical designs, these developments could contribute substantially to the commercial viability of EVs.

The requirements of the ideal EV battery may be summarized as follows.

- High specific energy (Wh/kg)
- High volumetric energy density (Wh/l)
- High power-energy ratio
- Long life
- Low cost
- High energy efficiency

The first three criteria determine vehicle performance; the remaining three directly affect the economics of vehicle operation. The achievement of all these requirements in a single battery design is the key to providing an acceptable battery for a commercially viable EV.

The lead-acid battery has a number of inherent characteristics that satisfy many of the criteria and compare favorably with those of other near-term candidates, such as the nickel-iron, nickel-zinc, and zinc chloride batteries: high volumetric energy density, high power-energy ratio, low cost, and high energy efficiency. An additional factor of major significance is the existence of a well-established infrastructure for lead-acid battery production, distribution, maintenance, and recycling. The demonstrations of improved specific energy and improved life, therefore, remain the chief barriers to the acceptance of the lead-acid battery as a viable candidate for future EV applications.

Despite these limitations, the lead-acid battery has been used successfully for many years in a wide range of mobile power applications, such as forklift trucks, golf carts, and mine vehicles. For these applications, batteries have been designed either for long life, which results in relatively low specific energy (1000–1500 cycles and 24 Wh/kg, typical for industrial equipment), or for higher specific energy, at the expense of shorter cycle life (33 Wh/kg and 300–400 cycles, typical for golf carts). The challenge to the EV battery developer is to obtain improved performance without compromising cycle life.

The most widely practiced method of improving the specific energy is the use of thinner plates assembled with reduced spacings. This approach effectively increases active material utilization by increasing the surface area–volume ratio. However, this results in reduced cycle life, as thin plates are more sensitive to the degradation mechanisms that occur with deep-cycle batteries (i.e., positive grid corrosion, shedding of active material, and sulfation of negative plates). The extent to which these occur in a given application is a complex function of many operating factors, such as rate and depth of discharge, operating temperature, and method of charging.

Acid stratification is an additional factor that negatively affects cycle life and is a result of electrolyte density changes during repeated charge-discharge cycling. Acid stratification accentuates degradation of the lower portions of the plates exposed to concentrated (high-density) acid from nonuniform discharge of the active materials and excessive local grid corrosion, as well as from negative active material sulfation. To minimize these effects, extensive overcharge is normally applied during battery recharge. Gas evolved through electrolysis agitates the electrolyte and eliminates stratification prior to the subsequent discharge. However, gassing itself is deleterious to life, weakening the positive active material structure and causing generalized positive grid corrosion. These effects are more pronounced in the higher specific energy golf-cart-type designs.

Each of the above factors contributes to the limited cycle life (approximately 200 cycles) obtained from golf-cart-type batteries used in EV applications. With an improved understanding of these degradation mechanisms and vehicle mission requirements, there have been a number of design approaches to develop longer-life, improved-performance lead-acid batteries. The most significant of these are a circulating electrolyte, an improved tubular plate, and a sealed, immobilized electrolyte. In-vehicle performance and life testing of systems incorporating each of these designs forms part of the EPRI–Tennessee Valley Authority (TVA) vehicle and component evaluation project (RP1136).

Circulating electrolyte

The improved state-of-the-art battery developed by Globe Johnson Controls, Inc., Battery Division, uses a circulating (pulsed) electrolyte concept similar to the airlift pump in submarine batteries. The system also incorporates a grid structure, which was computer-designed specifically for the EV's higher power requirements. The circulating electrolyte minimizes acid stratification, while reducing the requirement for extensive overcharge (from 20% to approximately 7%). Although more complex than conventional designs, this feature has a pronounced effect on cycle life. Tests using simulated EV driving profiles at the National Battery Test Facility at Argonne National Laboratory (ANL) have demonstrated over 500 cycles with specific energy values of 40 Wh/kg. This represents a significant improvement in the performance-life relationship of the lead-acid battery. The circulating electrolyte design also provides for improved heat dissipation during high-rate discharge and recharge. The first in-vehicle testing of this system is planned at TVA early in 1983. Further performance improvements are anticipated in the continuing development program at Globe with—for example—the introduction of composite plastic-lead grid structures. Evaluation of advanced developments will be carried out as an integral part of a test program recently initiated at ANL (RP2216).

Tubular-plate design

The approach used for many years in Europe to the problem of limited life in deep-cycle batteries has been to use tubular design positive electrodes. Here the active material is contained within tubes fabricated from woven fibrous materials. A central spine of lead alloy is used as current collector. Although the tubular-plate design is inherently more expensive to manufacture than the flate-plate design, it has unique characteristics that are beneficial in EV applications.

▫ For a given plate thickness, the active material in the tubular design has a greater surface area–volume ratio than the equivalent flat-plate design, resulting in improved active material utilization.

▫ The woven fabric tube provides an effective means of retaining the positive active material, thus decreasing the susceptibility to shedding.

Chloride Batteries Ltd. (U.K.) has demonstrated that a specific energy as high as 40 Wh/kg (5-h discharge rate) and a cycle life of 800 deep-discharge cycles can be obtained by optimizing the tube and spine configurations. In-vehicle evaluation of chloride batteries is planned at TVA early next year (the specific energy is expected to be lower than the 5-h rate value). Accumulatorenwerk Hoppecke's (West Germany) approach to the development of improved tubular-plate batteries has been to adopt a flat (oval) tube to increase the quantity of active material within a given plate thickness. Batteries based on this design now undergoing in-vehicle testing at TVA have shown no detectable performance decline during early operation. However, the specific energy delivered was low (24 Wh/kg at 75-A discharge), and this would appear to limit the current design to very short range applications.

Sealed design

The concept of a sealed design is particularly attractive for EV applications because it eliminates the need for battery maintenance. The approach taken by Gould Inc. has been to use an immobilized, starved electrolyte. In this design the separator layer contains a proportion of unfilled pores to allow for the flow of oxygen from the positive plates, where it is generated on charge, to the negative plates, where it is electrochemically reduced to form water. This limits the pressure buildup and permits a sealed operation. There are a number of additional advantages in this design concept—for example, electrolyte stratification is greatly reduced without the need for extensive overcharge and the improved mechanical stability of the immobilized electrode materials reduces shedding.

Six-volt modules developed for stationary energy storage (e.g., photovoltaic) have demonstrated lives of over 500 deep cycles during bench testing at a 5-h discharge rate. (The modules have not been designed to maximize specific energy.) Experimental battery packs of the same type are currently undergoing in-vehicle performance and life testing at TVA. In initial tests, however, several premature module failures occurred, primarily because of overheating during vehicle operation, highlighting a key limitation of the immobilized electrolyte design—the problem of heat removal during high-rate discharge and charge. Despite this limitation, the many intrinsic advantages of the sealed technology justify its development for EV applications with new design concepts that address the need for improved thermal management at the cell, module, and pack levels.

Jet Propulsion Laboratory (JPL) is currently developing a sealed deep-cycle battery design, similar in concept to the Gould design but using thinner, horizontally mounted plates with multiple tabs for improved current collection. Evaluation of this design for EV mission requirements is part of a test program recently initiated at JPL (RP2216). *Project Manager: Barry Askew*

WASTE HEAT RECOVERY FROM RESTAURANT AIR CONDITIONING SYSTEMS

Waste heat recovery from air conditioning systems in the commercial sector is emerging as a highly attractive opportunity for energy conservation and demand reduction. Restaurants (those facilities having electric water heaters) are the commercial sector group with the greatest potential savings in energy use and have the most attractive economics for the owner/operator because of the extensive air conditioning required and the large amounts of hot water used. A project was therefore undertaken to develop a handbook to assist utility company customer representatives in surveying a restaurant to determine if a waste heat recovery system is economically feasible. The handbook will also enable a contractor, designer, engineer, or utility company representative to design a waste heat recovery system.

In early 1978 EPRI initiated a study to assess the current state of the art and the extent to which the technology of energy conservation through waste heat recovery from air conditioning and refrigeration systems has been applied (EM-1348, Vols. 1 and 2). Specifically, this study addressed the application of the waste heat recovery technology in the residential, commercial, and industrial sectors with the following goals.

▫ Identify possible applications of existing or anticipated heat recovery system hardware, associated implementation and operational costs, and cost savings on the basis of reduced energy consumption and demand

▫ Identify barriers that prevent widespread application of the technology where it would be cost-effective and make recommendations for their removal

▫ Determine the overall impact on energy consumption, demand reduction, and cost savings if the technology is widely adopted

▫ Assess the impact on utilities if the technology is implemented on a major scale

The conclusions of this initial study were straightforward. Although significant energy savings can be obtained in the residential and industrial areas, the largest potential savings were identified in the commercial sector. A potential annual energy savings greater than 0.24 quadrillion Btu could be achieved by desuperheating hot refrigerant gases through existing waste heat recovery technology and readily available, off-the-shelf hardware. (Recovery of latent heat was not considered because of its lower temperature and the complexity of the required heat recovery system.)

Table 1 summarizes the potential energy savings available from facility groups in the commercial sector. In addition, analysis showed that when waste heat recovery systems are installed in many commercial facilities (those having electric water heaters and located in summer-peaking service areas), there is a net savings in the utility's cost of service because significant demand reductions coincide with the utility system peaks.

The study indicated that the cost-effectiveness of a large number of potential commercial applications would be very good. The cost payback periods for most applications ranged from one to five years, with a number of applications producing payback periods of one or two years. Although the technology was found to be cost-effective and technically viable for a wide range of commercial applications, it has not been widely implemented. The study concluded that the most significant single barrier preventing widespread penetration was the lack of user awareness of the technology—its potential for application and, specifically, the cost savings it could provide (60–80%). To eliminate this barrier, the study recommended the following.

- Provide general information on waste heat recovery systems, their installation, typical implementation and operational requirements, and typical energy/cost savings

- Provide application guidelines that delineate prime considerations in the selection of a system and address critical economic factors (e.g., the cost-effectiveness of integrating the installation of a waste heat recovery system with planned maintenance and/or modification or as an integral part of new construction)

- Provide reliable technical and economic data to rapidly assess the primary design or application and provide the potential user with accurate information on implementation costs and benefits

Near the end of the first phase of this study, utilities were surveyed to determine their interest, goals, and needs. The survey, which included representatives of 15–20 utilities (a cross section of utility size and geographic location), indicated strong support. The survey also ascertained that with only one or two exceptions, the utilities had little or no commercial sector customer-oriented information on heat recovery applications. Even the utilities that had acquired some information recognized that the available data pertained to a limited number of situations in their geographic regions and a more comprehensive consumer-oriented application and design information package would be of value. Current efforts in this area, therefore, focus on the development of a handbook that will include general information for potential users about associated costs and energy/cost savings that can be realized from heat recovery applications, as well as technical and economic data to be used by the utility representative, designer, or engineer in the analysis of critical application and design sensitivities and in system/hardware sizing and selection.

Table 1
POTENTIAL ENERGY SAVINGS FROM REFRIGERANT GAS DESUPERHEATING

Facility	10^{15} Calories/yr	10^{12} Btu/yr
Restaurants	4.0	15.8
Hospitals	3.2	12.7
Supermarkets	3.2	12.7
Hotels/Motels	1.9	7.5

To ensure the most cost-effective development, the initial scope of the handbook is limited to a high-potential application—restaurants. The data will be validated by field trials and may then be applied to the needs of a number of other commercial sector groups, such as hotels, motels, and supermarkets.

Restaurant survey

A critical step in the preparation of the handbook was a survey of restaurants to determine actual energy use and the factors that influence the economics of waste heat recovery system implementation. It was found that fast-food restaurants frequently use enough hot water to justify the installation of a waste heat recovery system. This fact was not expected and results in there being many more candidate facilities than originally envisioned. (Consideration of fast-food restaurants may account for up to 20,000 candidates for waste heat recovery systems.)

Full-service restaurants are almost always good candidates for a waste heat recovery system because of their large water-heating requirements and extensive use of air conditioning. Further, analysis of the survey data indicates that only a small number of basic waste heat recovery system concepts are needed to meet the needs of a very large percentage of restaurant applications because of the commonality of cooling system types, sizes, and uses, and hot water requirements.

Surveys of restaurants that had installed waste heat recovery systems uncovered several problems. Many could be classified as design errors, including overdesign (e.g., more valves and other hardware than needed for efficient operation); unsuitable and inadequate insulation; incorrect refrigerant and water pipe sizing; and inadequate storage volume (e.g., absence of a preheat tank, causing poor or no heat collection).

An important question answered during this study was the effect of a waste heat recovery system on the efficiency of an air conditioning system. A small but definable improvement (2–5%) occurs when properly designed waste heat recovery systems are combined with air-cooled air conditioners. However, installation of poorly designed waste heat recovery systems can prevent this improvement and even cause an overall reduction in efficiency. (This underscores the need for good design practice.)

The handbook

The approach used in the development of the design and/or analysis of a waste heat recovery system was tailored to address the problems encountered in the restaurant survey or otherwise identified in this project through analysis and interviews with vendors, restaurant operators, and air conditioning system manufacturers. An integrated, stepped sizing procedure is presented for each major component, based on calculated or measured air conditioning system operation and profiles of water-heating energy consumption. The handbook contains examples of the sizing procedures and provides guidance in the selection of ancillary equipment. It also includes sample designs and specification packages to ensure adoption of good design practice.

The economic feasibility analysis for a waste heat recovery system evaluates chain restaurants as well as one-of-a-kind establishments, concentrating on the amount of recoverable waste heat and the potential cost savings that would result from its recovery.

The handbook will be evaluated in the field during 1983. A revised version will incorporate any changes or additions found to be required during this evaluation period. *Project Manager: I. Leslie Harry*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

REVIEW OF PROBABILISTIC RISK ASSESSMENT STUDIES

In response to utility interest in the methods, results, and usefulness of probabilistic risk assessment (PRA), EPRI contracted with NUS Corp. to conduct a review of five PRA studies (RP2171-1). Three of the studies reviewed were sponsored by utilities: Consumers Power Co. for its Big Rock Point plant, Commonwealth Edison Co. for its Zion plant, and Philadelphia Electric Co. for its Limerick plant. The other two studies—for Grand Gulf and Arkansas Nuclear One, Unit 1—were sponsored by NRC. The contractor developed a standard questionnaire to gather information about the studies. The responses have been summarized, interpreted, and compared to gain valuable insights about PRA and about the critical needs for further methodology development.

The Reactor Safety Study (RSS), which was sponsored by NRC and published in 1975 as report WASH-1400, was the first comprehensive study to use PRA to examine the radiological risks associated with commercial LWRs. The study attempted to quantify the frequency and consequences of accidents associated with typical (representative) designs of a BWR and a PWR at representative U.S. sites. It was subjected both to extensive technical peer review and, as requested by Congress, to oversight review by a scientific panel called the Lewis committee.

Several PRAs have recently been completed for specific plants at specific sites, and many more are in progress. Motivated by a variety of objectives, these PRAs range in scope from limited adaptations of the RSS methodology and results (the RSS Methodology Application Program, or RSSMAP, studies) to full-scale PRAs that have introduced new methods in many ways different from those of the RSS. Also, the systems addressed by these studies have a variety of design features. Because of the diversity of the PRA studies and because they usually produce multivolume reports, it is difficult to comprehend and assess the variations in results without extensive scrutiny. Realizing that there is considerable interest among utilities regarding the PRA results—and also considerable confusion about such results and their validity—EPRI initiated RP2171-1.

Goals and methodology

The main objective of the project was to provide a summary of five comprehensive PRAs, together with an interpretation of the results that would be of benefit to both technical specialists and those in management.

To prepare the summary, a standard questionnaire was developed. Designed to cover all phases of conducting a PRA study, it addressed the selection and assessment of initiating events, event and fault tree construction and quantification, accident phenomenology, fission-product behavior, containment response, and ex-plant consequences. In addition, information about the techniques used for handling reliability data, human interactions, and common-cause failures was requested, as well as a detailed account of the exact quantities calculated and presented in the study results. Finally, the questionnaire addressed management aspects concerning study scope and level of detail, the effort and time expended, peculiar organizational or other difficulties encountered, the structuring of study interfaces, quality assurance, the design of documentation, and implemented or planned applications of study results.

The sponsors of the PRA studies delegated the overall preparation and coordination of responses to their study consultants. Wood, Leaver and Associates directed the effort for Big Rock Point; Pickard, Lowe and Garrick, Inc., for Zion; General Electric Co. for Limerick; and Sandia National Laboratories for both Grand Gulf (RSSMAP) and Arkansas Nuclear One.

To provide a high level of continuity and consistency, the same NUS specialists who formulated questionnaire sections collected, evaluated, and summarized the responses for those sections. In some instances it was necessary to supplement the responses with a limited study of the PRA reports. Through this process valuable commentaries and insights have been developed that should enhance the understanding of nuclear safety and lead to improvements in the conduct of PRA studies and in PRA methodology.

Observations and insights

The principal findings of the review are summarized in the project report now being prepared. The findings are grouped into three sections that focus on management and overview items, a comparison of study results, and methodology. The first two sections are intended especially for technical managers and the third for PRA practitioners. A discussion of several of the most significant observations follows.

The primary motivation for the utility-sponsored PRA studies was to resist an avalanche of real or potential regulatory-induced backfits. By and large, the application of PRA has been successful in providing a quantitative perspective on the relative impact of hardware and procedural changes in reducing risk. The hardware changes considered in the studies ranged over a wide spectrum, from relatively minor ones to such radical ones as a core ladle. It is significant to note that a core ladle was shown to provide less risk reduction than a relatively inexpensive modification to the containment spray system.

The potential for applying PRA results, insights, and methods in other areas of interest to a nuclear utility has been fully recognized—for example, in the training of engineering, licensing, and operating staffs; in improving plant availability; and in evaluating the risk of losing capital-intensive equipment. Although such applications have been made to some degree by all the utilities surveyed, most study sponsors have been preoccupied thus far with fulfilling their primary objective. The exception is Consumers Power, which has established a continuing risk management program at Big Rock Point.

It was found that a comprehensive assessment primarily limited to internal initiators can be performed by a team of experienced PRA practitioners with 10 to 12 man-years of effort, given essential utility support. It is believed, however, that by applying insights gained from completed studies and by exercising more effective management, resources can be better allocated and significant economies of effort can be realized.

The lack of scrutability of PRA results remains both a limit on the quality of review that can be performed and an obstacle to more widespread acceptance and use of PRA techniques. It is believed that sponsors and their PRA consultants could do a much better job of thinking through the purposes their PRA might serve and of designing the report documentation accordingly.

The five PRA studies reviewed were extremely diverse with respect to reactor type, power rating, age, containment, and site, as well as study scope, methodology, and assumptions. As a result, it was an enormous challenge to compare the results on some common basis. However, the quantification of the probability of severe fuel damage, including dominant accident sequences, is one area where comparisons can be made. Figure 1 shows major contributors to the probability of such damage for PWRs and BWRs.

It was not possible to quantitatively determine the exact reasons for variations in the PRA results and for deviations from the RSS results; it was, however, possible to identify general reasons attributable to reactor design and operation and to study methodology and assumptions.

Critical needs for PRA development were broadly classified into nine areas: scrutability, comparability and credibility, dependent failures and system interactions, human interactions, accident progression and containment integrity, radiological source terms and consequence analysis, equipment qualification, uncertainty analysis, and external events. *Project Manager: David Worledge*

HUMAN FACTORS ASPECTS OF PLANT MAINTAINABILITY

Nuclear plant maintenance work is usually performed adequately. However, EPRI studies have found that many plant outages have been caused or prolonged by human factors problems associated with maintenance or instrumentation and control activities (NP-309, CS-1760). Such outages can be translated into replacement power costs of $500,000 to $800,000 a day. As well as having important technical and financial implications, maintenance is increasingly becoming a regulatory concern. In recognition of the critical role of maintenance, EPRI is sponsoring a series of human factors projects designed to improve the effectiveness, reliability, and safety of power plant maintenance personnel and the equipment they service.

Initial survey

In 1977 EPRI awarded a contract to conduct intensive reviews of power plant maintainability for a sample of nine plants—five nuclear and four fossil fuel. A number of problem areas were identified and documented (in many cases with photographs). The reviews are reported in NP-1567; some of the major findings are summarized here.

It was found that maintenance workforce requirements were underestimated for nu-

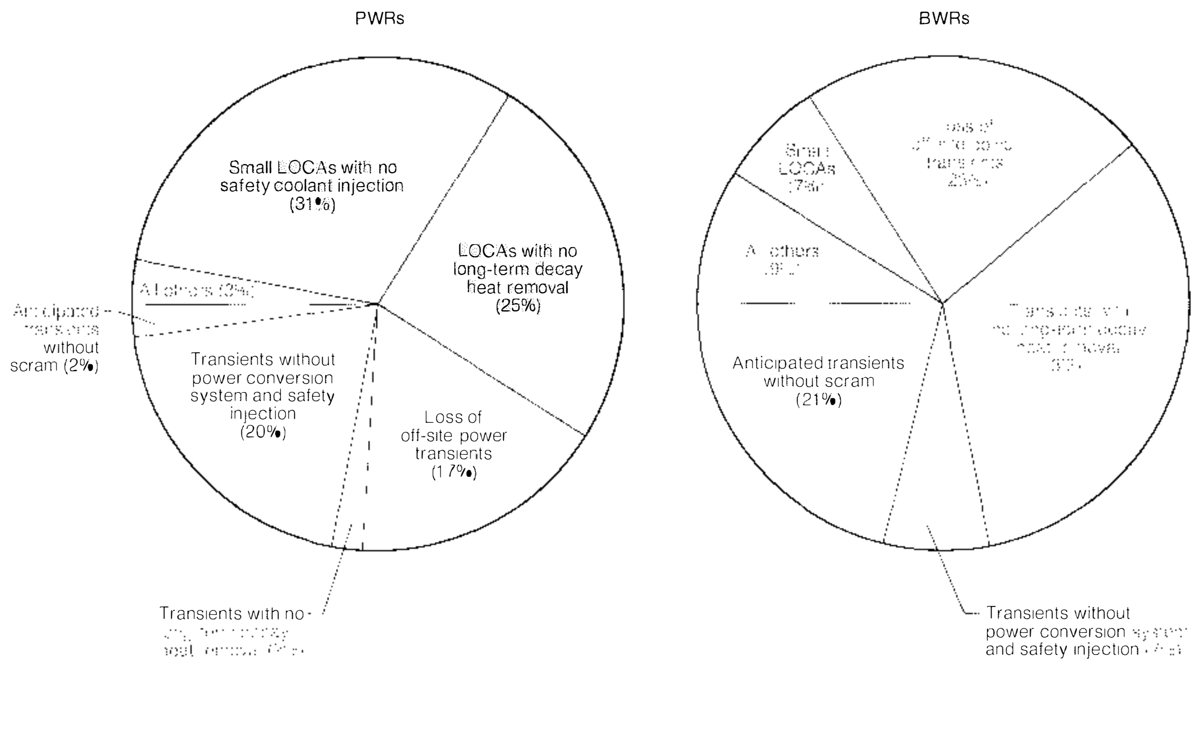


Figure 1 Major contributors to the probability of severe fuel damage, based on a review of PRA studies for two PWRs (Zion and Arkansas Nuclear One, Unit 1) and two BWRs (Grand Gulf and Limerick; Big Rock Point was excluded because its design is not typical). The shaded portion of each graph represents loss-of-coolant accidents (LOCAs), and the unshaded portion represents transients.

clear power plants designed 10–20 years ago. Consequently, maintenance facilities at these plants are generally overcrowded; a constant shuffling of plant space, the erection of temporary structures, and new construction are necessary to accommodate personnel. These problems are aggravated when personnel from outside contractors join the workforce during major outages.

The most universal complaint voiced by maintenance personnel is the difficulty of access to equipment requiring attention. The workers interviewed indicated that an average savings of 30% in overall maintenance time could be achieved if access to equipment were ideal or unrestricted.

Inadequate attention has been paid by designers to the body dimensions and strength limitations of maintenance personnel. Access openings are sometimes too small, instruments may be placed beyond normal viewing distances, and the force required to unbolt or move equipment may tax the capabilities of the repair crew. Also, systems and facilities are often not designed to accommodate personnel encumbered with the protective garments and gear required in radioactive areas.

The quality of maintenance activities was found to be adversely affected by a variety of environmental factors, including high noise levels; poor illumination, sometimes because of a failure to systematically replace expended lamps; extreme conditions in parts of the plant that are unsheltered (e.g., the turbine deck); and high temperatures, in some areas reaching 175°F (79°C) and above. Personnel reported a lack of effective thermal protection garments.

Some 80% of nuclear maintenance personnel reported problems with their plant communications system. The major complaints involved inadequate system capacity for the volume of communications traffic, especially during outages; inadequate coverage throughout the plant; and difficulties in overcoming high ambient noise levels.

Other important problems and concerns identified in the maintainability reviews are as follows.

- Rarely were maintenance personnel observed to use formal procedures in performing repair tasks, despite the fact that most maintenance errors have been attributed to faulty procedures or a lack of procedures.

- An inordinately high number of complaints regarding elevators, cranes, and other devices for moving people and equipment were reported. Cranes assume key importance during outages, and scheduling their use becomes a critical path item.

- Effective labeling and coding techniques are underutilized in power plants. A lack of contrast between legends and background may make labels unreadable. Another problem is missing labels—in time, 10–15% of the original labels may be lost.

- The orderliness, space, and organization of warehouses and toolrooms vary widely.

- Power plants offer many possibilities for industrial accidents—for example, steam burns, heat prostration, and falls from improvised work platforms or on slippery walking or climbing surfaces.

- Equipment systems and facilities are sometimes not properly designed to avoid inadvertent damage. For example, in the absence of formal access provisions, repairmen may use instrumentation racks or cable trays as natural stepping-stones. Or when the means for hoisting materials and equipment are inadequate, they may use a handy overhead pipe that was not designed for such a purpose.

- Although all the plants visited place great value on a systematic preventive maintenance program, only one plant had such a program in place. Other plants were constantly in a corrective maintenance, or catch-up, mode.

This initial survey revealed that much could and should be done to enhance existing power plants from the standpoint of maintainability. Several major architect-engineering firms and utilities report that they are now using NP-1567 for training and design review purposes.

Maintainability assessment methods

In response to this initial maintainability study, some utilities that had not participated asked EPRI to provide the tools and methods needed to conduct self-reviews of maintenance facilities and practices and to address the problems identified in NP-1567. As a result, EPRI awarded a contract for the development of data-gathering and maintainability assessment methods.

The product of this effort is NP-2360. It provides the reviewer with a detailed checklist based on the findings of NP-1567. The checklist questions are grouped into categories that parallel the sections of that report—for example, facilities, equipment maintainability, environmental factors, movement of personnel and equipment, anthropometrics and human strength, labeling and coding, and communications. For each checklist item, there is space for the reviewer to indicate compliance or noncompliance and record explanatory comments. To illustrate the checklist, here are some sample questions on equipment arrangement.

- Are equipment components arranged so that it is not necessary to disassemble adjacent units in order to reach malfunctioning components requiring maintenance attention?

- Are units that may have to be removed from an installation so located that they pass through in a straight, or moderately curved, line?

- Are components that weigh over 25 pounds installed within normal reach of the repairmen or technicians that must service the equipment?

- When a team effort is required to accomplish maintenance tasks, is sufficient clearance available to allow effective interaction of team members?

- When it is necessary or desirable to use vehicular or other movement or transportation aids, is sufficient clearance available to employ such aids?

- Are equipment systems designed so that repairmen and technicians can do their jobs without having to assume awkward working positions?

NP-2360 also presents a structured interview form to enable the reviewer to draw on the experience and insights of maintenance personnel. Other data-gathering tools discussed in the report are a task analysis method for reviewing work crew performance and equipment and facility design; special surveys in such areas as communications, illumination, and safety measures; the critical-incident technique for investigating accidents, errors, and near-mishaps; and an approach called the potential accident/damage analysis. Maintainability enhancement options and strategies are also presented.

Job performance aids

It has been proved that conventional procedures are not optimally efficient in a variety of situations. The military has conducted extensive evaluations of techniques for presenting procedural information to maintenance workers and has demonstrated the superiority of job performance aids (JPAs) for selected applications. JPAs are usually based on comprehensive task analyses of the jobs to be performed. They present step-by-step instructions in an easy-to-read text with many illustrations (Figure 2). Before being placed into operational use, draft JPAs are verified by subject matter experts and validated in trials with members of the user population.

EPRI sponsored a project to evaluate and demonstrate the potential for implementing JPAs in selected power plant applications. In addition to maintenance, JPAs were developed for these functional areas: instrumentation and control, systems operations, health physics and chemistry, and quality assurance. A total of 15 JPAs were prepared, and several instances of technology transfer involving these aids have been documented. The final report on this project, NP-2676, estimates the costs and benefits of JPA use and provides guidance for JPA implementation.

Anthropometric data base

In complex technological systems, the quality of the interface between man and machine has a direct and important influence on ultimate system performance. A key factor in the man-machine interface is the extent to which equipment and work areas are designed to accommodate the body dimensions of workers. As found in various EPRI human factors reviews, however, power plant designers have not used formal anthropometric data in a consistent manner (NP-309; NP-1118, Vol. 2; NP-1567).

In response to this problem, an in-house EPRI study was conducted to develop an anthropometric data base specific to the power plant industry—that is, one based on the body size variability of the men and women who are currently operating and maintaining power plants. The resulting data base, which has been published in NP-1918-SR, covers 21 body size variables (e.g., weight, stature, shoulder height, sitting eye height, elbow-grip length, hip breadth). For each variable the data base gives the mean value, the standard deviation, and values for the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles. The final report has been widely distributed and is in constant use as a design reference document.

Thermal protection garments

Earlier EPRI studies found that maintenance personnel are frequently required to work in unfavorable temperature and humidity environments. A number of problems are associated with such exposure. For example, it is not uncommon for a worker to be limited to 20–30 minutes of productive activity before he becomes completely fatigued. In response to this situation, EPRI has sponsored a project to evaluate alternative cooling concepts for safely increasing the period of productive work.

Three prototype garments were tested in a laboratory under controlled climatic conditions. The most promising one, a frozen-water garment, was then field-tested under operational conditions. This suit features a lightweight, easily donned garment that has many pockets for holding packets of ice. Initial field tests indicate that under typical temperature and humidity regimes, a worker's tolerance is significantly increased when wearing the garment. Twenty-four suits are already being used in cleanup operations at Three Mile Island. The final report on garment development and testing, NP-2868, is now in preparation.

Figure 2 This sample page from a job performance aid developed under EPRI contract for power plant application illustrates the easy-to-follow format of JPAs. The task, part of static calibration procedures for the control rod drive flow loop, involves the use of a digital voltmeter (DVOM).

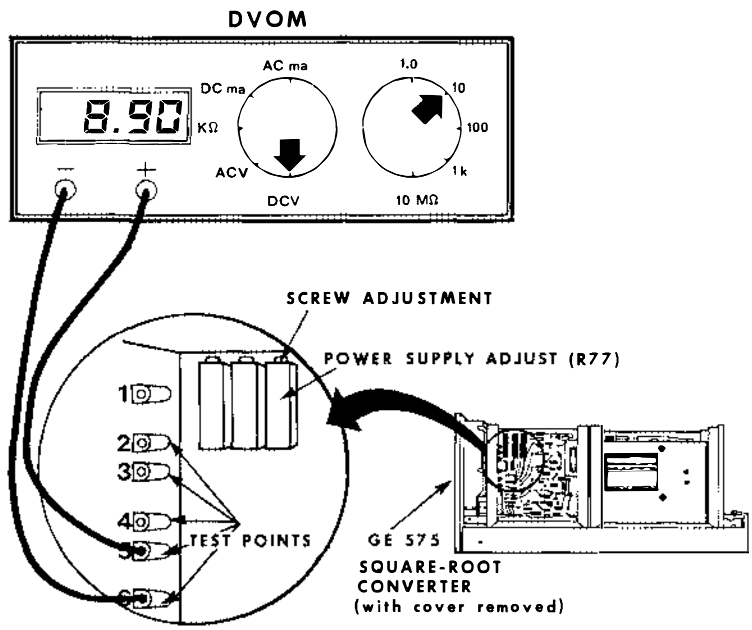
6.3 Adjust Power Supply

a. Connect DVOM to test points 6 (-) and 5 (+) on side of unit. If voltage registers 8.90 ± 0.03 skip to Step 6.4. If not, proceed as follows.

b. Locate power supply adjust (R 77) on circuit boards.

c. Use screwdriver to adjust output to 8.90 ± 0.03 volts. Disconnect DVOM.

d. Call your supervisor if output cannot be adjusted within specifications; otherwise proceed to 6.4.



Future efforts

EPRI studies have confirmed that nuclear plant maintenance personnel are dedicated and creative and that maintenance activities are usually performed adequately. As in other industries, however, some problems have been identified that are amenable to correction or improvement through R&D. These problems relate directly to technical, economic, or regulatory concerns. To meet this challenge, in 1982 EPRI initiated a four-year human factors maintenance program (RP2166) to explore solutions for the major problems that have surfaced to date. The first project to be funded under this program involves the development of a preventive maintenance model that utilities can adapt to the needs of specific power plants. Other research efforts being formulated include the development of maintainability design guidelines and guidelines for operations in high-stress environments. *Program Manager: Howard L. Parris*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1037-3	Verification and Application of Entrained-Gasifier Simulation Code	1 year	60.0	DOE *G. Quentin*
RP1197-5	Field Test of Upstream Reboiler for Direct-Flash Geothermal Power System	8 months	97.9	Bechtel Group, Inc. *E. Hughes*
RP1348-15	Strategies for Advanced Photovoltaic Research	8 months	99.5	Strategies Unlimited *E. DeMeo*
RP1415-7	Conceptual Design: High-Concentration Photovoltaic Array	9 months	348.8	Black & Veatch Consulting Engineers *R. Taylor*
RP2029-6	Evaluation of the BGC–Lurgi Gasifier for Combined-Cycle Electric Power Generation	1 year	197.7	The Ralph M. Parsons Co. *B. Louks*
RP2147-7	Selective Catalytic Hydrogenation of Polynuclear Heteroaromatic Basic Nitrogen Compounds	4 months	60.0	DOE *L. Atherton*
RP2272-4	EPRI–TVA Biomass Workshop	5 months	30.0	Battelle, Columbus Laboratories *S. Kohan*
RP2389-1	Fuel Gas Saturator, Experimental Control Analysis	13 months	235.4	General Electric Co. *G. Quentin*
Coal Combustion Systems				
RP1179-16	Use of Calcitic Limestone in Pressurized Fluidized-Bed Combustion	6 months	51.0	Argonne National Laboratory *S. Ehrlich*
RP1256-7	Technical and Economic Assessment: Selective Catalytic Reduction NO_x Control	5 months	50.0	Stearns-Roger Engineering Corp. *E. Cichanowicz*
RP1263-15	Washing PCB-Contaminated Soil	6 months	37.5	Acurex Corp. *R. Komai*
RP1402-15	Precipitator Fouling	6 months	43.5	Radian Corp. *R. Altman*
RP1645-10	Conceptual Design and Assessment: Pressurized Circulating Fluidized-Bed Boiler	4 months	58.4	Combustion Engineering, Inc. *S. Drenker*
RP1645-11	Conceptual Design and Assessment: Pressurized Circulating Fluidized-Bed Boiler	4 months	71.9	Lurgi Corp. *S. Drenker*
RP1648-7	Guidebook: Turbine Bearing Lubrication System, Maintenance Practices	18 months	201.2	Southwest Research Institute *T. McCloskey*
RP1689-12	Symposium: Condenser Technology State of the Art	10 months	33.9	Heat Exchanger Systems *I. Diaz-Tous*
RP1856-3	Failure Analysis of Fossil Low-Pressure Turbine Blade Group	8 months	170.0	Stress Technology, Inc. *T. McCloskey*
RP1871-6	Corrosion Chemistry of SO_2 Scrubbers	16 months	241.1	Battelle, Columbus Laboratories *B. Syrett*
RP1871-8	Economic Analysis: Materials for FGD Systems	7 months	49.9	Stone & Webster Engineering Corp. *T. Morasky*
RP1885-2	Reduction of Solid-Particle Erosion Damage in Utility Steam Turbines	25 months	1123.7	General Electric Co. *I. Diaz-Tous* *J. Stringer*
RP1893-1	Stress and Condition Analyzer	25 months	465.8	Combustion Engineering, Inc. *A. Armor*
RP2154-2	Evaluation: Retrofit Low-NO_x Combustion Systems	20 months	1130.7	Riley Stoker Corp. *M. McElroy*
RP2158-1	Boiler Tube Oxide Deposition Control by Dispersants	30 months	300.0	Columbia University *J. Dimmer*
RP2215-1	Low-Volume Solid-Waste Management, Phase 2	1 year	94.9	Radian Corp. *D. Golden*
RP2248-2	Causes of Materials Failure in FGD Systems	25 months	214.1	Radian Corp. *D. Stewart*

Number	Title	Duration	Funding ($000)	Contactor/ EPRI Project Manager
RP2300-1	Status Assessment: Biofouling Detection Monitoring Devices	6 months	68.0	Battelle, Columbus Laboratories *M. Miller*
RP2303-1	Evaluation: Atmospheric Fluidized-Bed Combustion Demonstration Projects	26 months	425.4	Bechtel Group, Inc. *C. Aulisio*
Electrical Systems				
RP1277-10	Transmission Line Wind Loading	10 months	88.7	The University of Oklahoma at Norman *P. Landers*
RP1277-11	Transmission Line Wind Loading, Data Evaluation	8 months	86.7	Texas Technological University *P. Landers*
RP1507-2	HVDC Circuit Breaker, Phase 2	14 months	953.9	Westinghouse Electric Corp. *J. Porter*
RP1917-1	Data Transfer and Conversion Upgrade of EPRI Power Flow Program	6 months	53.6	Boeing Computer Services, Inc. *J. Lamont*
RP1999-2	Transient Stability Assessment With Unbalanced Faults	14 months	51.6	Purdue Research Foundation *J. Mitsche*
RP1999-4	Modeling of External Networks for On-Line Security Analysis	16 months	53.0	Arizona State University *C. Frank*
RP2115-5	Critical Problems in Developing HVDC Converter Stations for Voltages Above 600 kV DC	9 months	100.0	Institut de Recherche de l'Hydro-Québec *S. Nilsson*
RP2236-2	Amorphous Metal Power Transformer	2 years	912.1	Westinghouse Electric Corp. *E. Norton*
Energy Analysis and Environment				
RP799-16	AC Field Exposure	1 year	137.1	Enertech, Inc. *R. Kavet*
RP863-4	End-Use Billing Development and Demonstration	6 months	50.0	Applied Management Sciences, Inc. *J. Chamberlin*
RP1491-3	Economic Controls of Utility Emissions	11 months	119.2	ICF Incorporated *A. Halter*
RP1743-5	Index and Synopsis of EPRI-Sponsored Research: Cooling-System Effects on Ponds, Lakes, and Reservoirs	6 months	34.9	Western Aquatics, Inc. *R. Brocksen*
RP1781-1	Strategic Planning Methods	4 months	62.0	Resource Planning Associates, Inc. *S. Mukherjee*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1826-12	Workshop: Risk Assessment in Ecology	13 months	57.8	Envirotest *A. Silvers*
RP1946-3	Radionuclide Transport and Risk Assessment	7 months	49.4	Purdue Research Foundation *R. Wyzga*
RP1955-2	Demand-Side Planning, Scoping Study	3 months	30.0	Battelle, Columbus Laboratories *A. Faruqui*
RP1955-3	Effect of Load Management on Generating System Reliability	14 months	25.6	Associated Power Analysts, Inc. *J. Chamberlin*
RP2046-5	Use of Artificial Streams for Toxicological Research	5 months	32.0	Science Applications, Inc. *R. Brocksen*
RP2088-1	Feasibility of a Mortality Study of Workers at Nuclear Power Plants	6 months	72.9	Oak Ridge Associated Universities *W. Weyzen*
RP2140-1	Slurry Pipeline Transport Alternatives	13 months	138.1	Dames & Moore *E. Altouney*
RP2141-3	Decision Framework for Cost-Benefit Analysis of Air Quality Standard: Radionuclide Emissions From Coal-Fired Power Plants	11 months	214.9	Woodward-Clyde Consultants *E. Niemeyer*
RP2155-1	Effects of Acid Sulfates on Macrophage Functions and Alveolar Clearance	2 years	440.6	New York University Medical Center *B. Smith*
Energy Management and Utilization				
RP1041-9	Site-Specific Evaluation of a Low-Btu, Fixed-Bed Coal Gasifier–Fuel Cell Power Plant	10 months	254.0	The Ralph M. Parsons Co. *D. Rastler*
RP1041-13	Evaluation of Conventional and Modified Stretford Technologies on Coal Gasification Gas Stream Cleanup	3 months	50.0	Pedco Environmental Specialists, Inc. *D. Rastler*
RP1191-12	Solar Heating and Cooling, Subprogram Planning and Technical Assistance	6 months	48.6	Altas Corp. *G. Purcell*
RP1201-27	Workshop: Building Energy Research	5 months	29.0	Science Applications, Inc. *T. Schneider*
RP1791-13	Construction Modifications and Operation of SEO Urschmitt Low-Pressure Test Facility	21 months	808.0	Société Electrique de l'Our SA *R. Schainker*
RP2033-11	Dynamic Control of Heat Pumps	15 months	147.1	The Trane Co. *J. Calm*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2036-11	Performance Analysis: Residential Thermal Storage Systems	10 months	197.5	Oak Ridge National Laboratory *V. Rabl*
RP2224-1	Floating Pressure Set-point Controls for Industrial Compressor Systems	16 months	289.2	Applied Energy Systems, Inc. *J. Brushwood*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP623-6	Crevice Corrosion of Lattice-Bar-Type Tubesheet Materials in Secondary Environments in Steam Generators	8 months	57.5	Stanford Research Institute *C. Shoemaker*
RP959-5	Experimental Study of Heat Transfer Enhancement	1 year	61.1	University of California at Los Angeles *A. Singh*
RP964-9	Laboratory Studies: Dynamic Response of Prototypical Piping Systems	20 months	285.0	Anco Engineers, Inc. *H. Tang*
RP1561-5	BWR Transient Test Documentation at Grand Gulf Nuclear Power	19 months	34.5	Middle South Energy, Inc. *P. Bailey*
RP1571-2	Optimization of PWR Water Treatment—Oxygen Suppression	3 years	375.8	Atomic Energy of Canada Ltd. *T. Passell*
RP1571-4	PWR Secondary Water Treatment—Corrosion Product Filtration	34 months	405.1	Atomic Energy of Canada Ltd. *T. Passell*
RP1571-5	Conceptual Design Options for Improving PWR Secondary Side Water Treatment	50 months	747.8	Gibbs & Hill, Inc. *T. Passell*
RP1702-6	Risø Transient Fission Gas Release	3 years	189.4	Risø National Laboratory (Denmark) *D. Franklin*
RP1757-16	Pipe Instability Demonstration Rig	13 months	47.5	Fracture Proof Design Corp. *T. Marston*
RP1757-18	Microstructure of Weld Metal	1 year	66.5	Lehigh University *T. Marston*
RP1761-18	Documentation and Preparation of a Production Version of BNL—TWIGL	10 months	126.3	Brookhaven National Laboratory *G. Lellouche*
RP1929-10	Evaluation of the Variability in the Stress Corrosion Cracking Susceptibility of NiCrMoV Turbine Disk Steels	3 years	702.7	Westinghouse Electric Corp. *A. Giannuzzi*
RP1930-4	Water Chemistry Measurements at Ringhals-1	16 months	99.5	ASEA—Atom *M. Fox*
RP1930-5	Effect of BWR Hydrogen Injection on Fuel Cladding	3 months	28.6	Atomic Energy of Canada Ltd. *D. Franklin*
RP2012-6	Development of Nonchemical Decontamination Techniques	14 months	249.8	Quadrex Corp. *H. Ocken*
RP2060-4	Stress Relief Cracking in Alloy Steels	11 months	79.8	University of Pennsylvania *R. Jones*
RP2060-5	High-Purity Steels for Utility Components, Property Improvement of Steel Castings	30 months	117.0	Case Western Reserve University *A. Roberts* *A. Jaffee*
RP2062-8	Cost Comparisons, On-Site Spent Fuel Storage Options	5 months	56.5	Boeing Engineering & Construction *R. Lambert*
RP2062-9	Prediction of Zircaloy Cladding Failure Under Dry Storage Conditions	18 months	92.1	Stanford University *R. Williams*
RP2065-4	Transition of Large Development Plant, Technical Integration Office	3 months	194.3	Boeing Engineering & Construction *R. Johnson*
RP2120-1	Aerosol Transport Through Reactor Primary Coolant System	21 months	325.0	SRI International *M. Merilo*
RP2120-3	Aerosol Transport Through Reactor Primary Coolant System	17 months	100.0	University at Buffalo Foundation, Inc. *M. Merilo*
RP2126-3	BWR Suppression Pool Signal Validation	5 months	62.1	The Charles Stark Draper Laboratory, Inc. *M. Divakaruni*
RP2129-1	Isotopic Analysis of LWRStack Effluents, Using Cadmium Telluride Detectors	22 months	199.5	Radiation Monitoring Devices, Inc. *G. Shugars*
RP2134-1	Antifoulant Coatings for Condenser Cooling Systems	16 months	45.7	Diamond Shamrock Corp. *N. Hirota*
RP2240-2	Fuel Consolidation Demonstration Program	30 months	2070.5	Northeast Utilities Service Co. *R. Lambert*

R&D Staff

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1266-33	Influence of Microstructure and Texture on the Properties of Titanium Alloys	2 years	32.0	Technische Universitat *R. Jaffee*
RP2253-1	Boiler Pressure Parts, Life Estimation	4 years	697.5	Combustion Engineering, Inc. *R. Viswanathan* *J. Dimmer*

New Technical Reports

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

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

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

Standing orders for free copies of reports in EPRI program areas or Technical Summaries of reports for each EPRI technical division may be placed by EPRI member utilities, libraries of U.S. federal, state, and local government agencies, and the official representative of any foreign organization with which EPRI has an information exchange agreement. For details, write to EPRI Technical Information Division, P.O. Box 10412, Palo Alto, California 94303.

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

ADVANCED POWER SYSTEMS

Simulation of a Texaco Gasifier: Unsteady-State Model

AF-1179 Final Report (RP1037-1), Vol. 2; $7.50

This volume describes the extension of a simple steady-state model of an entrained pilot plant gasifier to include the simulation of transient operation. Model results are compared with unsteady-state data from experimental tests on a 15-t/d pilot plant gasifier. Analyses of transient and steady-state data are presented, and simulation program modifications are discussed. Model validation and future efforts are also addressed. The contractor is Texaco, Inc. *EPRI Project Manager: G. H. Quentin*

Stationary Gas Turbine Catalytic Combustor Development Program: Preliminary Design Report

AP-2584 Final Report (RP1657-1); $18.00

A study was conducted to assess the feasibility of developing a practical and reliable catalytic combustion system for utility combustion turbines. Eight conceptual combustor designs were evaluated for their potential to meet specific emissions, performance, and reliability goals. On the basis of these evaluations, a single, fixed-geometry design was identified as the most promising concept. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: L. C. Angello*

Assessment of Distributed Solar Power Systems: Issues and Impacts

AP-2636 Final Report (RP1995-1); $16.50

This report discusses some of the technical and economic impacts of solar power systems. The questions addressed include isolated operation, power quality, line safety, metering options, user purchasing criteria, structure and installation costs, marketing and product distribution costs, and interconnection costs. The development of an interactive computer program for easy calculation of allowable system prices and allowable generation equipment prices is also described. The contractors are Science Applications, Inc., and Systems Control, Inc. *EPRI Project Manager: R. W. Taylor*

Phase Formation During Supercritical Solvent De-ashing of Solvent-Refined Coal

AP-2645 Final Report (RP774-1); $21.00

This report describes an experimental study to develop phase data for various coal liquid–solvent systems. Five systems were examined: Wilsonville solvent-refined coal–heptane, Wilsonville SRC–toluene, Wilsonville SRC–pyridine, asphaltene-toluene, and preasphaltene-toluene. Ratios of solvent to coal liquid were also investigated for each system. Solvent properties are discussed, as well as the determination of maximum solubility and phenomena associated with the rejection of coal liquids from supercritical solvent. The contractor is West Virginia University. *EPRI Project Manager: N. C. Stewart*

Role of Design Complexity in Forecasting Reliability and Availability for Generating Units

AP-2693 Final Report (RP1923-2); $13.50

This report examines the relationship of design complexity to reliability and availability performance for fossil fuel electric power generating units. Multivariate regression analysis techniques were applied to data gathered from a representative sample of generating units, and 12 predictive relationships or equations were developed. Guidelines for applying the predictive relationships, including confidence limits, were also developed. The contractor is Arinc Research Corp. *EPRI Project Manager: Jerome Weiss*

Proceedings of the Seventh Annual EPRI Contractors' Conference on Coal Liquefaction

AP-2718 Proceedings (WS82-102); $39.00

This report contains papers presented at the 1982 EPRI Contractors' Conference on Coal Liquefaction, held in May in Palo Alto, California. The papers discuss the operation of large coal liquefaction pilot plants, two-stage liquefaction, and liquefaction-related research. They also summarize current and future possibilities for coal liquids. *EPRI Project Manager: H. E. Lebowitz*

Parameter Monitoring for Corrosion Control of Utility Gas Turbines

AP-2737 Final Report (RP643-1); $13.50

This report presents the results of field work on the hot corrosion of gas turbines. The study was conducted to confirm (1) that a corrosion control system operated in a field environment would reliably measure the accumulation of corrodents ingested in an engine, and (2) that removal of the accumulated corrodents would effectively inhibit hot corrosion. The primary cause of hot corrosion is identified, and methods for reducing corrosion are described. The contractor is United Technologies Corp. *EPRI Project Manager: R. L. Duncan*

Dynamic Simulation of a Single-Stage Entrained-Flow Coal Gasifier

AP-2740 Final Report (RP1037-2); $19.50

This report describes the development of a transient, multidimensional computer model to simulate phenomena occurring in the general class of single-stage entrained-flow gasification reactors. The theoretical formulation of the model is presented, and several calculations are described. Possible implications for scale-up and gasification–combined-cycle operation are noted. The contractor is S-Cubed. *EPRI Project Manager: G. H. Quentin*

COAL COMBUSTION SYSTEMS

Coal-Oil Mixture as a Utility Boiler Fuel: COM Preparation

CS-2309 Final Report (RP1455-2), Vol. 2; $15.00

This volume documents work to assess the market potential and the cost of preparation for a commercially produced coal-oil mixture (COM) fuel suitable for use by electric utilities. A methodology for price estimation is presented, and pricing components—costs for materials, transportation, and manufacturing—are discussed. A detailed base case with specific assumptions about production plant size and location, feedstock pricing, and COM composition is described. The contractors are Atlantic Richfield Co. and Bechtel Group, Inc. *EPRI Project Manager: R. K. Manfred*

Porous Dike Intake Evaluation

CS-2594 Final Report (RP1181-1); $13.50

Results are presented from a study to develop and demonstrate a porous dike intake design that eliminates entrapment and substantially reduces entrainment. The following parameters were evaluated: hydraulic performance, fouling, siltation, and screening effectiveness for zooplankton, ichthyoplankton, and finfish. The contractors are New England Power Service Co. and Marine Research, Inc. *EPRI Project Manager: J. A. Bartz*

Evaluation of Pulse Energization on a Hot-Side Electrostatic Precipitator

CS-2634 Final Report (RP1868-2); $10.50

The use of pulse energization to improve the performance of a hot-side electrostatic precipitator (ESP) was evaluated at Gulf Power Co.'s Lansing Smith station. This report details the coal, ash, and flue gas analyses; electrical parameters; mass collection efficiencies; and particle charge measurements. The results show that pulse energization enhances ESP performance, although the pulse's effect on the ash layer and the mechanisms involved are poorly understood. The contractor is Southern Research Institute. *EPRI Project Manager: Walter Piulle*

Technical and Economic Feasibility of Ammonia-Based Postcombustion NO_x Control

CS-2713 Final Report (RP783-2); $25.50

The feasibility of postcombustion NO_x control for pulverized-coal-fired utility boilers is evaluated.

Preliminary designs are described for three ammonia-based selective catalytic reduction processes and one selective noncatalytic reduction process for application to a hypothetical 500-MW plant. The major capital equipment components of each design are identified, and capital costs are estimated. The report also discusses additional R&D that is necessary before full-scale continuous application can be considered. The contractors are Stearns-Roger Engineering Corp. and Radian Corp. *EPRI Project Manager: J. E. Cichanowicz*

Seminar Proceedings: Municipal Solid Waste as a Utility Fuel

CS-2723 Proceedings (WS81-261); $12.00

This report contains the proceedings of an EPRI seminar on municipal solid waste that was held in May 1982 in Miami Beach, Florida. The seminar focused on reporting the status and recent experience of municipal and regional refuse-to-energy projects involving utilities. Both cofiring of refuse-derived fuel in utility boilers and energy recovery from refuse in dedicated boilers were addressed. The satisfactory initial startup of a dedicated refuse-fired facility that uses a rotary water-wall combustor was also discussed. *EPRI Project Manager: C. R. McGowin*

Vibration and Balance Problems in Fossil Plants: Industry Case Histories

CS-2725 Final Report (RP1266-27); $15.00

Actual field case histories involving turbines, generators, fans, pumps, and electric motors are presented to demonstrate some practical uses of vibration analysis. Each case history covers problem definition, problem symptoms, test data and observations, corrective actions taken, final results, and conclusions and recommendations. The results show that a vibration analysis program can be a valuable tool for troubleshooting and for predictive maintenance of power plant equipment. The contractor is Public Service Co. of Indiana, Inc. *EPRI Project Manager: A. F. Armor*

ELECTRICAL SYSTEMS

Field Evaluation of New Outdoor Polysil Insulators

EL-2635 Interim Report (RP1281-1); $12.00

This report describes the successful development, fabrication, and initial testing of 69-kV Polysil insulators. It discusses (1) electric field plotting by computer for insulator designs with embedded electrodes, capacitors, and resistors, and (2) the development of mold materials, casting methods, and instrumentation for continuous leakage-current monitoring. Results from 25 field stations representing the wide variety of environmental conditions found in the United States and Mexico are presented. The contractor is Lindsey Industries, Inc. *EPRI Project Manager: E. R. Perry*

Improved Motors for Utility Applications

EL-2678 Final Report (RP1763-1); Vol. 1, 16.50; Vol. 2, $22.50

An industry assessment study was conducted to develop a data base on utility motor applications, operating factors, failures, failure causes, and failure impacts on generating station operation. The data collected are discussed, and motor failures are related to units, utilities, manufacturers, and applications. Volume 1 presents the statistical and engineering analysis of the data. Volume 2 contains the data and additional analysis. The contractors are General Electric Co. and Booz, Allen & Hamilton, Inc. (subcontractor for Volume 2). *EPRI Project Manager: D. K. Sharma*

Development of a Leak Location System for Use on Underground Transmission Cable

EL-2679 Final Report (RP7869-1); $18.00

This report describes a study to evaluate methods for locating leaks of dielectric fluid from buried high-voltage cable systems. Two primary types of techniques are discussed: those for rapidly isolating the leak within a manhole section and those for pinpointing the location of the leak. Conclusions drawn from field tests of conventional and novel leak location techniques are presented. The contractor is Power Technologies, Inc. *EPRI Project Managers: S. Kozak and T. J. Rodenbaugh*

Transmission Line Grounding

EL-2699 Final Report (RP1494-1); Vol. 1, $33.00; Vol. 2, $24.00

This report describes a generalized approach to transmission line grounding. Typical problems are presented to illustrate how to design transmission line grounds by using the computer programs developed for this project. Volume 1 describes analytic methods, measurement techniques, and design methodology. Volume 2 contains design charts for typical structure grounds. The contractor is Safe Engineering Services, Ltd. *EPRI Project Manager: J. H. Dunlap*

HVDC System Control for Damping of Subsynchronous Oscillations

EL-2708 Final Report (RP1425-1); $18.00

This report documents the development of a subsynchronous damping controller for use in inhibiting oscillations in an HVDC converter current control loop. The system parameters affecting the oscillations—the dynamic interaction between HVDC transmission systems and turbine generator shaft torsional systems—are described. A specification outline for a subsynchronous damping controller that can be added to an existing HVDC converter control system is included. The contractor is General Electric Co. *EPRI Project Manager: S. L. Nilsson*

Forced-Vaporization Cooling of HVDC Thyristor Valves

EL-2710 Final Report (RP1207); $25.50

This report describes the development of the analytic modeling tools, experimental data, and empirical correlations necessary to design a two-phase cooling system for thyristor valves. It covers the development of basic thermal-hydraulic information in small-diameter tubes with Freon-113; prototypical passage and heat sink tests; dielectric breakdown in transfer lines; alternative fluids for thyristor cooling; a thermal-hydraulic demonstration module; and a preliminary hydraulic layout. The contractor is General Electric Co. *EPRI Project Manager: Gilbert Addis*

Laboratory and Field Testing of a Production-Type Current-Limiting Protector

EL-2724 Final Report (RP1142-2); $10.50

This report summarizes the objectives and the results to date of a project to develop and field-test a fully operational, cost-effective current-limiting protector (CLP). Background information and requirements, including a review of the CLP principle and the consequences of fault currents, are presented. The CLP body, assembly, and laboratory performance are described, as well as trial installations and field experience. The development effort resulted in consistent manufacturing processes for reliable CLP systems. The contractor is Phoenix Electric Corp. *EPRI Project Manager: J. W. Porter*

ENERGY ANALYSIS AND ENVIRONMENT

Proceedings of Coal Transportation Modeling Workshop

EA-2551 Proceedings (RP1219-8); $22.50

Papers from a joint EPRI–DOE workshop on coal transportation modeling held in December 1981 in Palo Alto, California, are presented. The papers address two transportation cost models; a model of county-level coal supply and demand; a non-network-based model of interregional coal supply, demand, and price; three network-based coal flow assignment models; five comprehensive models of transportation interactions in the domestic coal industry; and a model of international coal flows. The contractor is Argonne National Laboratory. *EPRI Project Manager: E. G. Altouney*

Review of World Hydrocarbon Resource Assessments

EA-2658 Final Report (TPS80-763); $15.00

This study reviews assessments of world oil, natural gas, and oil shale resources made between the end of World War II and the end of 1980. Details are provided on the methods used in developing these assessments, geographic coverage, time horizons, and major assumptions (e.g., about discovery rates and recovery factor). Conclusions on the current state of knowledge concerning each of these hydrocarbon resources are presented. The contractor is the International Institute for Applied Systems Analysis. *EPRI Project Manager: Jeremy Platt*

Industrial Electrification Potential: Case Studies of the Primary Metals and Glass Industries

EA-2761 Final Report (RP1215-2); $9.00

This report summarizes a study of the potential for increased electrification by industry in response to the effects of technology development, natural gas shortages, and increasing natural gas prices. The study focused on the metals industry and the glass and ceramic industry, which both have a critical production need for high-temperature heating and exacting chemical control. Their existing production processes are described, along with alternative electrified processes. The costs and savings of potential shifts to electrified processes are identified. The contractor is Charles A. Berg Associates. *EPRI Project Manager: S. D. Braithwait*

Proceedings: Workshop on Compensatory Mechanisms in Fish Populations

EA-2762 Proceedings (RP1633-2); $10.50

This report contains a summary of an EPRI workshop on compensatory mechanisms in fish populations that was held in February 1982 in Palo Alto, California. The participants recommended two broad conceptual frameworks for the development of a research program and identified major research activities. These plans were later integrated into a final research program, which is included here. The contractor is Science Applications, Inc. *EPRI Project Managers: R. W. Brocksen and J. S. Mattice*

Aggregate Residential Electricity Demand: Methods for Integrating Over Declining-Block Rates

EA-2767 Final Report (RP1361); $12.00

This report describes two methods of modeling aggregate residential electricity demand: one that integrates individual household demands over tastes and income and another that requires numerical integration by means of Monte Carlo simulation. Two problems in modeling such demand—accounting for declining-block rates and aggregating over diverse customer preferences to obtain an aggregate measure of demand—are discussed. Results from one model are compared with results from earlier models. The contractor is National Economic Research Associates, Inc. *EPRI Project Manager: S. D. Braithwait*

ENERGY MANAGEMENT AND UTILIZATION

Aquifer-Based CAES: Preliminary Design and Site Development

EM-2351 Final Report (RP1081-3), Vols. 4–9; priced per vol.

This nine-volume report documents a study that assessed the viability of an aquifer-based compressed-air energy storage (CAES) facility. Volume 4 covers aquifer geology; it discusses the suitability of air storage in an aquifer, the geologic structure of the selected site, and aquifer testing. Volume 5, in two separately bound and priced parts, addresses turbomachinery design. Part 1 discusses the development of a design approach for the combustion turbine heat cycle and describes the major mechanical equipment for the CAES facility; Part 2 documents the computer programs and subroutines written to provide a general-purpose modeling tool for a CAES plant. Volume 6 addresses the balance-of-plant design, and Volume 7 covers environmental, safety, and licensing considerations. Volume 8 describes the airflow models used for aquifer performance prediction and CAES system analysis. Volume 9 presents the engineering and construction schedule, the capital cost estimate, and corresponding cash flow requirements. The contractors are Sargent & Lundy Engineers and Public Service Co. of Indiana, Inc. *EPRI Project Manager: R. B. Schainker*

Evaluation of Industrial Advanced Heat Recovery/Thermal Energy Storage Systems

EM-2573 Final Report (RP1275-1), Vol. 2; $33.00

Potential industrial applications of waste heat recovery systems using thermal energy storage were investigated. This volume presents detailed industrial process data, technical and cost information on pertinent equipment, proposed designs for advanced heat recovery/thermal energy storage systems, and a complete discussion of the study procedures and results. The contractor is United Technologies Research Center. *EPRI Project Manager: I. L. Harry*

Electrical Heating of Forging Billets

EM-2644 Final Report (RP1201-18); $12.00

This report describes a proposed new process for heating forging billets that uses a homopolar generator. The process is evaluated in relation to furnace and induction heating, and comparative economic factors are discussed. The contractor is the University of Texas at Austin. *EPRI Project Manager: I. L. Harry*

Review of Industrial Energy Data Bases

EM-2647 Final Report (RP1965-1); $13.50

A project was undertaken to evaluate the accuracy and reliability of existing industrial energy data bases and to determine their applicability to utility and EPRI information needs. This report presents a comparative analysis of 11 major data bases. An executive summary addresses background, relevant EPRI programs, utility information needs, objectives and findings, and directions for further work. The contractor is Synergic Resources Corp. *EPRI Project Manager: I. L. Harry*

1981 Survey of Utility Load Management, Conservation, and Solar End-Use Projects

EM-2649 Final Report (RP1940-1), Vol. 1; $22.50

This report summarizes information collected in 1981 on utility-sponsored load management, conservation, and solar end-use projects. It describes the type and level of activities being conducted by individual utilities and the various systems, devices, and techniques being used. It also lists equipment manufacturers and utility contacts from whom more detailed project information can be obtained. The contractor is Energy Utilization Systems, Inc. *EPRI Project Manager: V. K. Rabl*

Evaluation of Dual Energy Use Systems

EM-2695 Interim Report (RP1276-8); Vol. 1, $7.50; Vol. 2, $21.00

Volume 1 summarizes objectives, major tasks, and results to date of a project to evaluate DEUS. Volume 2 details the results, covering a cogeneration data base and case studies; computer programs for screening and evaluating cogeneration options; the conceptual design and analysis of cogeneration systems for the pulp and paper industry, enhanced oil recovery, and distillation columns; a survey of district heating in the United States; and information on European district heating. The contractor is Synergic Resources Corp. *EPRI Project Managers: S. D. Hu and R. L. Mauro*

Pulp Mill Design for Effective Cogeneration

EM-2697 Final Report (RP1276-6); $19.50

This report describes the design and evaluation of alternative cogeneration systems for pulp and paper production processes. Field data from two mills provided a measure of current industry energy use. The impact of process and operating changes on energy consumption at new mills is examined. The steam and power design options for three cases—no cogeneration, thermal match, and maximum cogeneration—are evaluated, and the economics of each case analyzed. The contractor is KPFF Consulting Engineers. *EPRI Project Managers: S. D. Hu and R. L. Mauro*

Cogeneration Systems Design and Analysis: Enhanced Oil Recovery

EM-2714 Interim Report (RP1276-9); $15.00

This report documents the first two tasks of a study to design and evaluate promising cogeneration systems for enhanced oil recovery. It describes site selection and preliminary cogeneration system selection. Data on the technical approaches developed thus far are given, and those approaches selected for more detailed study are indicated. The contractor is RMR Associates. *EPRI Project Managers: S. D. Hu and R. L. Mauro*

NUCLEAR POWER

LOCA Hydroloads Calculations With Multidimensional Nonlinear Fluid-Structure Interaction

NP-1401 Final Report (RP1065), Vol. 3; $25.50

This volume presents modifications to the three-dimensional STEALTH and WHAMSE computer codes used in fluid-structure interaction studies. It also describes the qualification of the three-dimensional methodology by comparison of calculations with experimental results. The contractors are Intermountain Technologies Inc.; Science Applications, Inc.; and Northwestern University. *EPRI Project Manager: R. N. Oehlberg*

PWR FLECHT–SEASET 21-Rod Bundle Flow Blockage Task Data and Analysis

NP-2014 Topical Report (RP959-1); Vol. 1, $40.50; Vol. 2, $60.00

This report presents data from the 21-rod bundle flow blockage task of the full-length emergency cooling heat transfer–separate-effects and system-effects test program. Volume 1 presents an introduction, a description of blockage shapes and configurations, a system description, test results, a limited data analysis, conclusions, and several appendixes. Volume 2 contains appendixes on instrumentation error analysis, calculation techniques, heater rod thermocouple locations, enhancement factors of reflooding tests, and temperature history calculations. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: K. H. Sun*

Guide to Generation Availability Evaluations and Decisions

NP-2169 Final Report (RP1391-8); Vol. 1, $25.50; Vol. 2, $28.50

This report—an edited, integrated account of previously reported work on availability engineering—covers analysis and calculations, use and interpretation of results, and program implementation. Volume 1 describes in detail the principles and practices of availability engineering and decision analysis for improved power plant productivity. Volume 2 focuses on the implementation of the basic analytic methods within an availability program and presents case study examples of both deterministic and probabilistic applications. The contractor is Los Alamos Technical Associates, Inc. *EPRI Project Manager: J. M. Huzdovich*

Safeguarded Fabrication and Reprocessing (SAFAR)

NP-2631 Interim Report (RP1578-2); $13.50

This report describes the design, safeguards, and diversion-resistant characteristics of an integrated nuclear fuel reprocessing and fabrication plant. Called the SAFAR facility, this plant for mixed-oxide fuel fabrication is based on an innovative design that facilitates the remote handling of plutonium and reduces the quantity of in-plant rework material. The contractor is Exxon Nuclear Co., Inc. *EPRI Project Manager: R. W. Lambert*

Diversion-Resistance Assessment Bases

NP-2632 Interim Report (RP1578-2); $13.50

This report describes the development of a semiquantitative approach to diversion-resistance assessment. The approach entails the evaluation of a series of physical attributes, including density of accessible plutonium, the gamma activity associated with the plutonium, and the degree of difficulty associated with converting the plutonium into a weapon. It also involves the use of a subjective evaluation process based on a Delphi expert group approach. The contractor is Exxon Nuclear Co., Inc. *EPRI Project Manager: R. W. Lambert*

Effect of Water Fogs on the Deliberate Ignition of Hydrogen

NP-2637 Final Report (RP1932-1); $10.50

This report documents an experimental evaluation of the effects of water fog density, droplet diameter, and temperature on the lower flammable limit (LFL) of hydrogen-air-steam mixtures. Various nozzles were tested. The results indicate that the LFL for hydrogen in air at 20°C is only marginally higher with fog than without. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: Loren Thompson*

Boiling in Narrow Crevices in Steam Generators

NP-2638 Final Report (RPS134-1); $21.00

This report describes an experimental and analytic study of the heat transfer characteristics and mechanisms associated with boiling in the tube–support plate crevices in steam generators. The results indicate that there are three distinct boiling regimes: isolated bubble, coalesced bubble, and dryout (steam in contact with the tube). A theoretical model was used to describe the extent of these regimes. The contractor is the University of Michigan. *EPRI Project Manager: C. L. Williams*

Repeatability of TREES Rotor Bore Inspection System

NP-2640 Interim Report (RP1570-2); $10.50

The repeatability of near-bore flaw detection and sizing by the turbine rotor examination and evaluation system (TREES) was examined. Data were also collected manually by using the bore ultrasonic characterization system (BUCS). The results indicate that TREES consistently detected flaws in the near-bore region, while corresponding BUCS data show large measurement spreads in each flaw classification. The contractor is J. A. Jones Applied Research Co. *EPRI Project Manager: G. J. Dau*

Environmental Crack Growth Measurement Techniques

NP-2641 Final Report (RP2006-3); $10.50

This report presents an evaluation of a reversing dc electrical potential method for the measurement of crack extension. As part of an effort to improve capabilities for predicting the behavior of flaws in nuclear plant materials and environments, this method was adapted for in situ application to artificially introduced defects in a high-temperature water environment. An analytic model was developed to relate measured electrical potentials to changes in the crack size and shape. The contractor is General Electric Co. *EPRI Project Manager: J. D. Gilman*

Predictions and Measurements of Isothermal Airflow in a Model Once-Through Steam Generator

NP-2643 Topical Report (RPS179-1); $25.50

This report documents thermal-hydraulic data previously acquired from tests in a model once-through steam generator with unheated (isothermal) air as the working fluid. The data include velocity and pressure distributions and flow patterns. The feasibility of lane blockers was assessed. Measured local velocities and pressure profiles were compared with THEDA code predictions for five model configurations. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. L. Williams*

Validation of Real-Time Software for Nuclear Plant Safety Applications

NP-2646 Final Report (RP961); $13.50

A methodology for producing reliable software for nuclear plant safety applications was developed and then demonstrated in a realistic on-line application. Details are presented on the software requirements, specification, coding, and testing. The verification and validation efforts are also described, including specification reviews, code walk-throughs, and final independent testing. The effectiveness of the methodology is evaluated on the basis of error data, manpower requirements, and user judgments. The contractor is General Research Corp. *EPRI Project Manager: A. B. Long*

Reflux Condensation and Operating Limits of Countercurrent Vapor-Liquid Flows in a Closed Tube

NP-2648 Interim Report (RP1160-3); $9.00

This report presents a study of reflux condensate flow phenomena, which are important in the event of a small-break loss-of-coolant accident in a nuclear reactor. A thermosyphon apparatus was used to determine the key parameters associated with the reflux mode of operation. Also, a theoretical study was conducted to determine the condensation heat transfer coefficient. Three different limits observed in the experiment—dryout, boiling, and oscillating flow—are discussed. The contractor is the University of California at Berkeley. *EPRI Project Manager: J. P. Sursock*

Hydrogen Evolution Monitoring as a Measure of Steam Generator Corrosion

NP-2650 Final Report (RPS117-1); $9.00

This report describes the development and testing of an on-line hydrogen-monitoring procedure that can quantify corrosion hydrogen release rates, thus enabling early detection of denting in steam generators. The procedure, which uses the Cambridge Mark IV dissolved-hydrogen analyzer, monitors main steam and feedwater hydrogen concentrations during normal power operation. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. E. Shoemaker*

Loads on Steam Generator Tubes During Simulated LOCA Conditions

NP-2652 Final Report (RPS144-1); $46.50

This report describes work performed to verify the CEFLASH digital computer code modeling of hydrodynamic loads on steam generator tubes during a loss-of-coolant accident (LOCA). It presents the results of a series of blowdown tests performed for different operating and boundary conditions. Experimental data are compared with the predicted transient pressure histories and the differential pressure history across the tube span. Data are also compared with predicted structural responses in the bend region. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: C. L. Williams*

Duplex Fuel Pellet Manufacturing Feasibility Study

NP-2653 Final Report (RP1581-6); $10.50

This report summarizes an assessment of the feasibility of manufacturing co-pressed duplex fuel pellets. Manufacturing studies were performed to optimize the process flow sequence for producing duplex pellets and to quantify the increased fuel fabrication costs associated with these pellets. Engineering analyses were also performed to assess the nuclear, thermal, and mechanical performance of duplex pellets. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. G. Franklin*

Effects of Hydrazine and pH on Corrosion of Copper-Alloy Materials in AVT Environments With Oxygen

NP-2654 Final Report (RPS196-1); $9.00

This report documents a study to quantify secondary-side material corrosion under typical feedwater train conditions and to develop ways to further limit corrosion. Specifically, tests were conducted to improve knowledge of the effects of pH, dissolved oxygen, and hydrazine on copper-alloy corrosion. On the basis of these tests, the alloys CDA-706 (90% Cu, 10% Ni) and CDA-443 ADM (admiralty brass) are not recommended for use in feedwater heaters when there is concern for corrosion-product transport. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Coit*

Reload Safety Analysis Methodology and Code Package Uncertainty Analysis: Amplification of Statistical Bases

NP-2657 Final Report (RP1761-4); $9.00

This report supplements EPRI NP-2577, which summarizes the statistical techniques suggested for use with the EPRI reactor analysis support package (RASP). The classification of uncertainty components is detailed, and recommendations (including monitoring and protection system setpoint analyses) are made for future prototypical computations using RASP. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: G. S. Lellouche*

Steam Generator Blowdown Filter Testing

NP-2659 Final Report (RPS109-1); $16.50

This report details the testing of one graphite and two electromagnetic high-temperature filters in the steam generator blowdown line of an operating nuclear plant. The filters were investigated as a means of reducing the amount of corrosion products sent to the steam generators and of improving the ability to remove those that do reach the generators. The test revealed that the electromagnetic filters were acceptable for use in the secondary system except in fluid systems with very low corrosion-product concentration. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: R. L. Coit*

Fire Tests in Ventilated Rooms: Extinguishment of Fire in Grouped Cable Trays

NP-2660 Interim Report (RP1165-1); $10.50

This report describes work to determine the automatic sprinkler design density necessary to extinguish a developing fire in a grouped-cable-tray installation. It discusses the results of four preliminary tests and four extinguishment tests using cables with polyethylene insulation and polyvinyl chloride jackets. The tests were conducted in a specially designed, ventilated room. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: Joseph Matte III*

In-Air Vibration Analysis of TMI-2 Once-Through Steam Generator Tubes

NP-2692 Topical Report (RPS140-1); Vol. 1, $10.50; Vol. 2 (microfiche only), $6.00

This report summarizes and interprets in-air vibration test data for the B once-through steam generator tubes at Three Mile Island, Unit 2. It discusses the determination of tube resonant frequencies and mode shapes for randomly selected tubes before steam generator operation. Volume 1 is the main body of the report, and Volume 2 (appendixes) contains records of all measurements. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. A. Steininger*

ATHOS: Computer Program for Thermal-Hydraulic Analysis of Steam Generators

NP-2698-CCM Computer Code Manual (RP1066-1); Vol. 1, $16.50; Vol. 2, $13.50; Vol. 3, $19.50

This report presents a detailed description of ATHOS, a computer code for the three-dimensional thermal-hydraulic analysis of steam generators. Volume 1 covers the mathematical formulation, physical models, and the method of solution. Volume 2, the programmer's manual, describes programming methodology, the code structure and logic, and the main subroutines. Volume 3, the user's manual, presents user-oriented modeling information, sample problem details, input-output descriptions, and sample output. The contractor is CHAM of North America, Inc. *EPRI Project Manager: G. S. Srikantiah*

Electrochemical Behavior of Ferrous and Ferric Ions in EDTA/N_2H_4 Solutions

NP-2701 Topical Report (RPS127-1); $7.50

As part of an effort to develop a process for chemically removing corrosion products from the secondary side of PWR steam generators, a project was initiated to develop a solvent system (and application techniques) for removing corrosion products at temperatures below 200°F. This report discusses laboratory testing conducted to understand the interaction of the solvent with the magnetite portion of corrosion-product deposits. Electrochemical measurements were made to study the conditions controlling the behavior of ferric and ferrous ions in solutions of EDTA and hydrazine (N_2H_4). The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. S. Welty, Jr.*

Rhodium In-Core Detector Sensitivity Depletion, Cycles 2–5

NP-2707 Interim Report (RP1397-1); $9.00

This report discusses the data gathered during fuel cycle 5 at Oconee-2 for the rhodium self-powered neutron detector sensitivity depletion experiment. An analysis of the data and a revised rhodium depletion curve for all four cycles of the experiment (Oconee cycles 2–5) are presented. Conclusions and recommendations are included. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: H. G. Shugars*

ABAQUS–EPGEN: General-Purpose Finite Element Code

NP-2709-CCM Computer Code Manual (RP964-5, RP1550-1), Vol. 1; $55.50

This report discusses ABAQUS–EPGEN, a general-purpose finite element computer code designed specifically to serve advanced structural analysis needs. Volume 1, the user's manual, covers the program terminology, analysis procedures, the element library, material modeling options, input specifications for model data and history data, user subroutines, input specifications for the postprocessor, the format for the computer-readable file, and postprocessing options. The contractor is Hibbitt, Karlsson and Sorensen. *EPRI Project Manager: H. T. Tang*

Radiological Impact of Clad and Containment Failures in At-Reactor Spent-Fuel Storage Facilities

NP-2716 Final Report (RP2062-1); $9.00

This report evaluates the range of fuel cladding and secondary containment failures that could occur before there would be a significant impact on the site boundary radiation exposure limit. It includes sample calculations used to examine the sensitivity of a dry storage system's ability to meet the acceptable rates presented in NRC guidelines. The results strongly indicate that dry storage systems can be built and operated with considerable margin of safety relative to normally acceptable release limits. The contractor is S. Levy, Inc. *EPRI Project Manager: R. W. Lambert*

Performance Measurement System for Training Simulators

NP-2719 Final Report (RP769); $15.00

This report describes the methodology and implementation of the prototype performance measurement system (PMS), software capable of running on a power plant training simulator in order to automatically record data on operator actions and plant responses. Results of research conducted with these data are summarized, several potential research applications are reported, and suggestions are made for improving the usefulness of PMS installations. The contractor is General Physics Corp. *EPRI Project Managers: J. F. O'Brien and H. L. Parris*

Evaluation of Irradiation Response of Reactor Pressure Vessel Materials

NP-2720 Final Report (RP1553-1); $13.50

The results of a project to develop improved radiation embrittlement forecasting techniques are summarized. The effects of chemical composition (both alloying and residual elements) and microstructure (product form) were assessed. Radiation embrittlement trend curves were statistically developed to provide predictions for transition temperature shift and upper-shelf drop. Separate trend curves were established for base materials (plates and forgings) and weld materials. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: T. U. Marston*

Containment Integrated Leak-Rate Testing Improvements

NP-2726 Final Report (RP1390-1); $18.00

This report details an investigation of methods for quickly and successfully conducting integrated leak-rate tests within a power reactor containment system. Details are given on the three project phases: an analysis of reports covering 27 containment leak-rate tests, the development of test guidelines, and the implementation of the guidelines to assess their effectiveness. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: T. M. Law*

Review of Proposed Instrumentation for Measuring Water Level as a Means of Detecting Inadequate Core Cooling in PWRs

NP-2727-SR Special Report; $15.00

A review is presented of instrumentation concepts and systems for measuring parameters that might indicate an inadequate core-cooling condition in PWRs. NRC requirements of such systems, evaluation criteria, and a detailed review of each proposed concept and developed system are included. *EPRI Project Managers: P. G. Bailey and Mati Merilo*

Nondestructive Method to Evaluate BWR Control Blade Performance

NP-2730 Final Report (RP1628-1); $13.50

This report details the development of a nondestructive method for determining the loss of B_4C powder from BWR control blades and the evaluation of the method at three nuclear reactors. The site measurements demonstrated that the equipment could routinely detect the loss of B_4C from failed control blade tubing, but they suggest the need to improve the way the station computer computes blade exposures when the blade is inserted less than 3 ft into the core. The contractor is National Nuclear Corp. *EPRI Project Manager: Howard Ocken*

Solid Radwaste Radionuclide Measurements

NP-2734 Final Report (RP1568-1); $18.00

Methods employed at U.S. nuclear power plants to assay low-level solid radwaste are reviewed to identify those aspects of the assay process that have substantial improvement potential and to determine ways to develop more effective methods. Practices at 41 nuclear stations are discussed, and in-depth reviews performed at 14 sites are described. Recommendations for future efforts, particularly regarding adherence to proposed regulations, are included. The contractor is NWT Corp. *EPRI Project Manager: M. D. Naughton*

BWR Radiation Control: Plant Demonstration

NP-2752 Interim Report (RP1934-1); Vol. 1, $15.00; Vol. 2, $16.50

This report presents results from the first year of a project to assess techniques for the control of radiation fields in an operating BWR. Extensive sampling and chemistry monitoring systems were installed to evaluate the plant's chemistry status and the effects of program-implemented changes. Volume 1 documents the first year's activity and contains a review of past operational, chemistry, and radiation-level data as a historical reference base. Volume 2 contains appendixes of raw data. The contractor is NWT Corp. *EPRI Project Manager: M. D. Naughton*

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