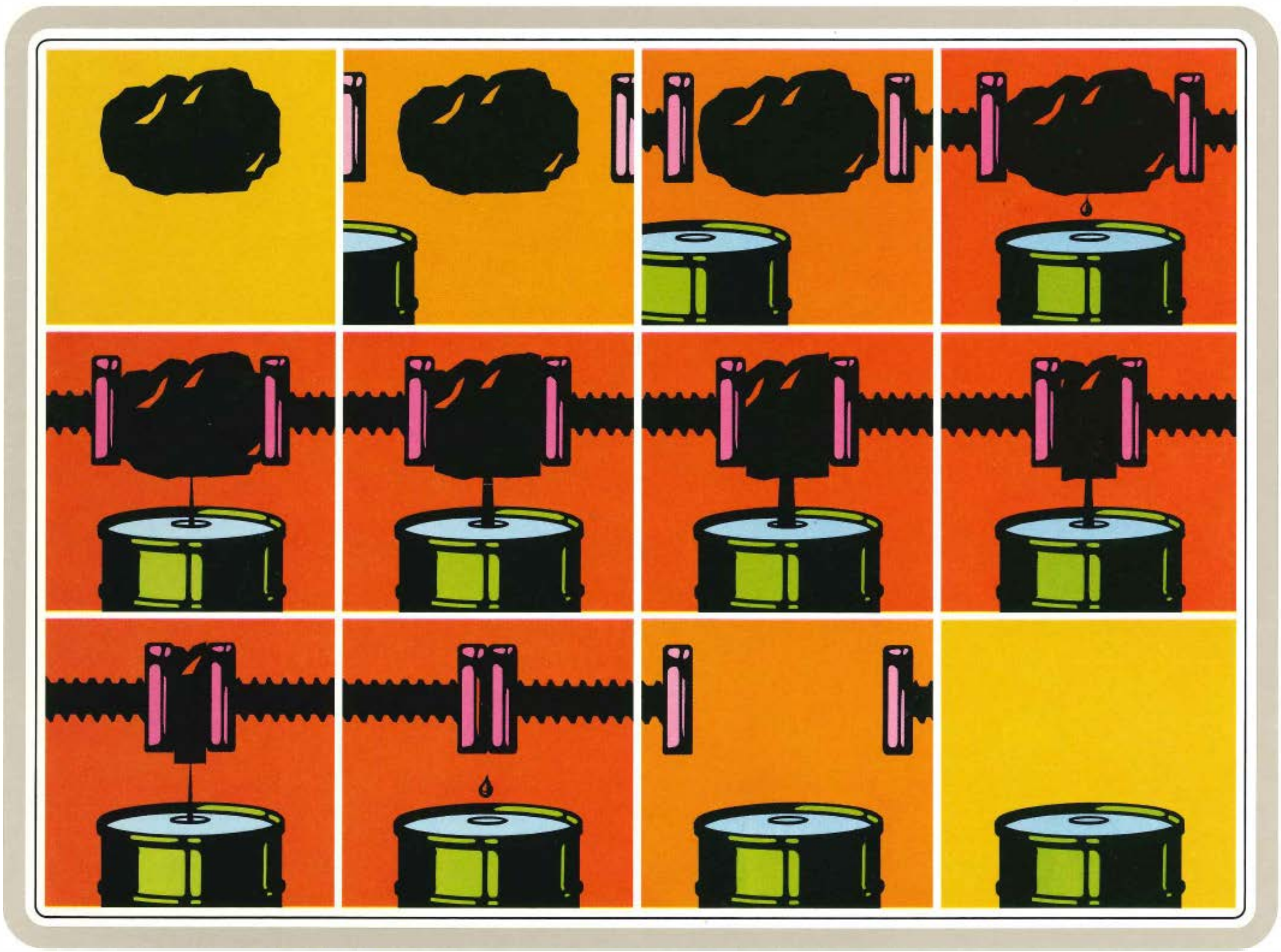
Oil From Coal

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

SEPTEMBER
1978



EPRI JOURNAL is published by the
Electric Power Research Institute.

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: Coal in a chemical vise—pressure, heat, and hydrogen transform solid fuel to a clean-burning liquid for utility boilers and turbines.

EPRI JOURNAL

Volume 3, Number 7 September 1978

Coal Liquefaction Incentives

Are electric utilities the key to early commercialization of coal liquids? At first blush, one would say the question is preposterous. The electric utility industry consumes less than 10% of the nation's liquid fuels. And as coal liquefaction processes are developed, the production of synthetic gasoline for transportation will surely come first, as a means to reduce our foreign oil imports. But look again. How quickly and in what other markets might coal liquids first be used? To address these questions, one must consider the situation from three standpoints: the utility industry's need, the supplier's attitude, and the fuel mix produced from coal liquefaction.

There is pending legislation and strong sentiment among many national leaders that may combine to phase out the use of petroleum fuels by the electric utility industry in both new and existing power plants. But we can't afford to retire all our oil- and gas-fired plants prematurely and at the same time meet reasonable generation expansion objectives. The capital requirements would be overwhelming. Also, we already have a capacity imbalance on some utility systems—that is, baseload units (coal and nuclear) that are uneconomic for cycling or midrange duty but are having to be operated in this mode. This is where coal-derived liquid fuels can play an economically attractive role in the generation mix.

Fuel suppliers (primarily oil companies) think first of markets for gasoline substitutes rather than markets for electric utility fuels. The capital costs of coal liquefaction plants will be high (per unit of capacity) and it is likely that the production cost for coal liquids will be greater than for petroleum products (even those refined from offshore or shale oil) until the 1990s. In addition, the threat to divest the petroleum industry of its coal holdings reduces its willingness to commit itself to an aggressive plan for coal liquids commercialization.

An often overlooked aspect of coal liquefaction is that 50–60% of the raw coal liquids produced are basically utility-grade fuel oils. Although somewhat different in composition from No. 5 fuel oil or residual oil, these synthetics should have potential for direct substitution under existing electricity utility boilers. Further, we believe that with minimal additional refining, they can be made compatible with combustion turbines. Thus, the fuel produced by coal liquefaction is a "natural" utility fuel.

On these three bases we conclude that electric utilities are indeed the likely first customers for a substantial fraction of coal liquids production. They are thus the key to early commercialization of liquefaction processes. This is why EPRI has joined with others to accelerate the construction of pilot plants and the planning for demonstration and pioneer plants that will be first to yield fuel in commercial quantities.

Of course, there are many unanswered questions about the costs of production, fuel handling, stack emissions, and so on. A critical nontechnical question may be, "Can electric utilities show that coal liquids are truly economical for midrange duty and thereby obtain regulatory commission approval to pay a premium price for them?"

Also, what is the proper stimulus from the electric utility industry to accelerate the commercialization of coal liquids? Should utilities own or partially finance the construction of demonstration and pioneer plants? Should they guarantee a floor for coal liquid prices?

We don't have all the answers but we're convinced that the foreseeable electric utility market is the key to development of this very important domestic resource.

Dwain F. Spencer, Director
Advanced Fossil Power Systems Department
Fossil Fuel and Advanced Systems Division

Authors and Articles

Last winter, after meeting with the deputy secretary of DOE, a group of electric utility chief executives asked EPRI to evaluate the technical status, development risk, and production potential of processes that yield liquid fuels from coal.

Dwain Spencer, Seymour Alpert, and Ronald Wolk of the Advanced Fossil Power Systems Department took on the assignment, and their concise 18-page response was produced in March. It was quickly seen by knowledgeable readers to be one of EPRI's most conclusive position papers in its five-year history.

"Scaling Up Coal Liquids" (page 6), by feature editor Ralph Whitaker, is based on that report and on discussion with its authors. The article traces a flowsheet of liquefaction development that should methodically transform today's three most promising process streams into an initial commercial production flow of half a million barrels a day by 1990.

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Characterized by new steels and exotic alloys, new water and fluid chemistries, and high environments of flow, temperature, pressure, and radioactivity, a modern power plant is a place where subtle forms of corrosion can take their toll. The cost implications of plant outage are thus a marked incentive for fast, thorough, and expert attention to corrosion problems. These problems have created a need for "Managing Corrosion Control" (page 14). Thomas O. Passell reviews the EPRI origins of the Corrosion Advisory Committee, of which he is now vice chairman; describes its intensive, candid mode of operation; and focuses on a few of the corrosion phenomena that have come under committee scrutiny.

Tom Passell's academic background is chemistry: a BS in 1951 from Oklahoma State University and a PhD in 1954 from the University of California at Berkeley. He has since built a career in radiochemistry, measurements, and diagnostics, largely as related to nuclear reactors. Passell was with SRI International for 13 years and with Lockheed Missiles & Space Co., Inc., for 4 years. He joined EPRI 3 years ago and is now a project manager for corrosion technology in the Nuclear Power Division.

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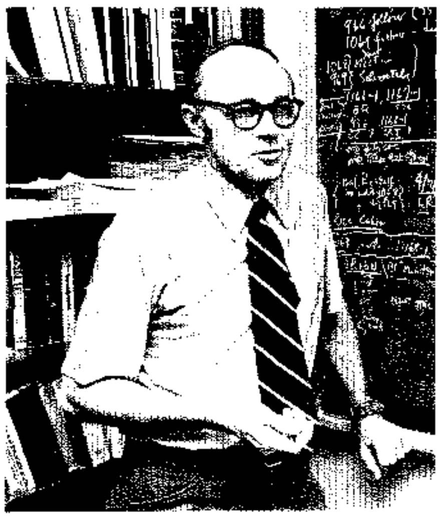
Because EPRI is chartered to focus on electric utility R&D, one might conclude that only EPRI can communicate and interpret that R&D, especially to audiences beyond its own members. Not so, points out the chairman of EPRI's Communications Advisory Committee. Utilities themselves have a natural bond of common interest with their customers that can be reinforced with an appropriate technical story.

"Don McCammond: Renewing Confidence" (page 20) presents the man and the viewpoint—and cites some specifics from Vepco, where McCammond is public relations vice president. *Journal* staff writer Stan Terra conducted the interview and wrote the article.

Passell



The nation's electric utilities were burning oil at the rate of 1.5 million barrels a day in 1976. Last year the National Electric Reliability Council compiled a report on generating capacity additions planned by utilities and converted those data into a forecast of oil use in 1986. The figure is 2.4 million barrels a day—up 60% in 10 years. EPRI estimates suggest that under certain conditions utility oil use could go even higher in subsequent years.

Whether these figures flatly forecast utility demand or only suggest a direction of growth if petroleum continues to flow, they contradict national policy proposals by which the White House and Congress seek to constrain—or even eliminate—oil firing by utilities. How can these figures and proposals be reconciled?

One functional answer is synthetic oil from coal—any of several similar liquid hydrocarbon fuels that can be formed in conversion processes that bring together coal, hydrogen, oxygen, and heat. The basic processes exist today; the need is to develop and scale up one or more of them to commercial reality.

Electric utilities are vitally interested in coal liquefaction technology because many of them have major investments in oil-fired generating plants that can economically work out their productive lives only on liquid fuels. Also, liquefaction processes have the built-in potential to remove such troublesome coal constituents as sulfur and nitrogen, thus yielding clean-burning fuels.

The key point is that the new fuels must be "in place" as a price-competitive supply when needed. Scaling up coal liquids is thus one means (offshore wells and oil shales are others) to reconcile the impending clash between liquid fuel demand and liquid fuel availability.

Pricing the potential market

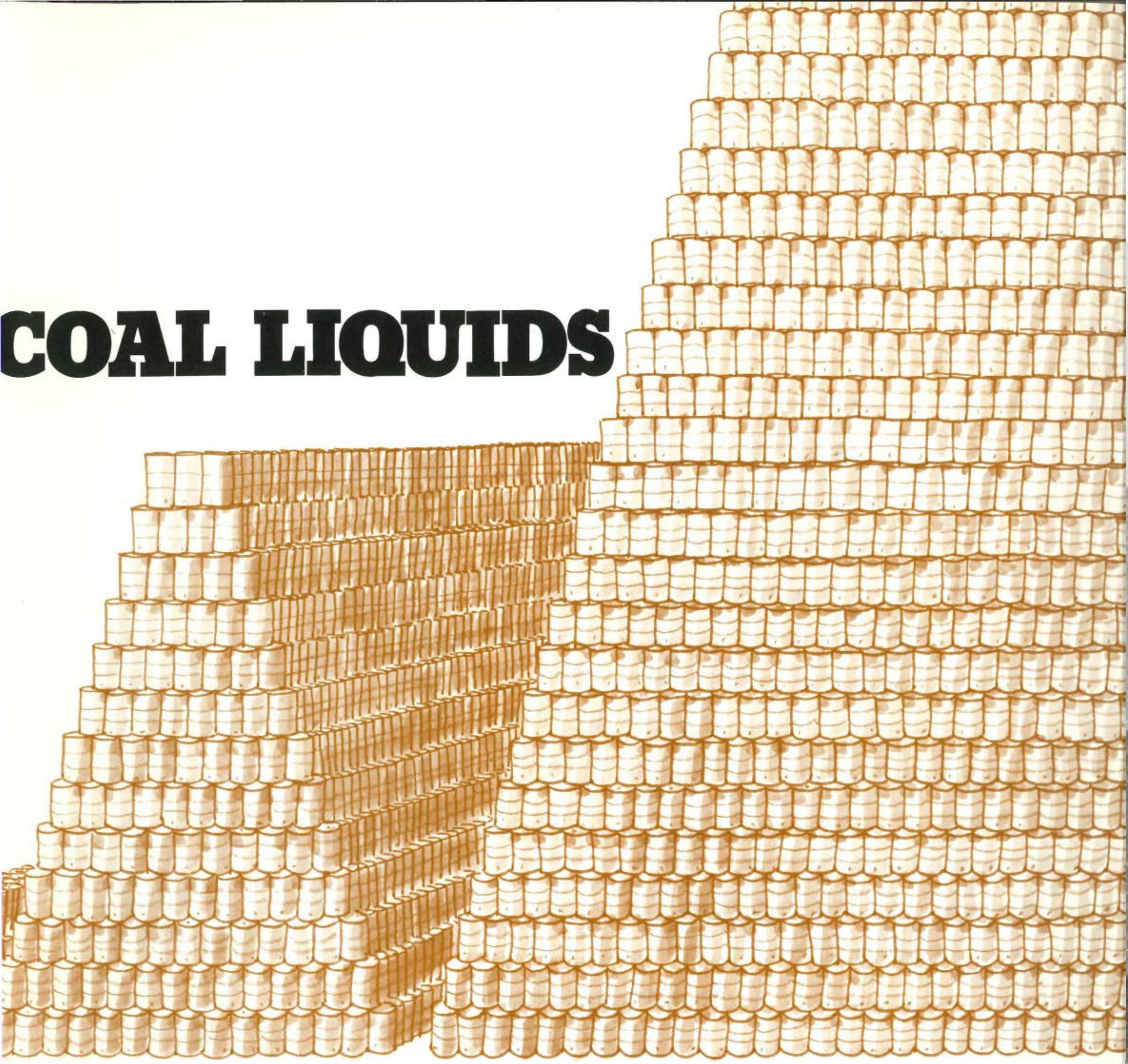
EPRI studies recently reported in the *Journal* suggest that coal liquids may well compete with conventional oils in the 1990s. "Market Potential for New

SCALING UP

Today's only pilot plant produces 75 barrels of coal liquids a day. Aggressive development of pilot and demonstration plants for three coal liquefaction processes can boost that volume by 1990 to 450,000 barrels a day from nine commercial facilities. And the signs point to a ready market among utility power plants that need a substitute for petroleum fuels.

Bench-scale Experiments	Process Development Units	Pilot Plant
Scientific proof	Research and development	Engineering confirmation
1960	1973	1977–1980
Up to 6 gal/d	3–9 bbl/d	75–1800 bbl/d
$5 million	$25–50 million	$100–250 million

COAL LIQUIDS



Demonstration or Pioneer Plant	Commercial Facilities
Integrated and economical operation	Competitive fuel volume and price
1983–1987	1990
20,000–60,000 bbl/d	450,000 bbl/d
$700 million–$1.4 billion	About $11.3 billion

Coal Technologies" (May 1978, pp.19–26) characterized the price sensitivity foreseen for coal liquids: at $3 per million Btu ($18 per barrel), there is a potential utility market of 2.5 million barrels a day in the year 2000, but at $4 per million Btu ($24 per barrel), a market of only 60,000 barrels a day—a difference of nearly 98%. It's important to recognize that these prices are in 1975 dollars. Both the prices and the cited fuel volumes assume unhampered market availability of petroleum and coal liquids.

But will that assumption hold? World oil production may peak out in the interim, or the price of oil may escalate from today's $13.50 per barrel. Either circumstance would create greater utility market potential for coal liquids. On the other hand, greater domestic oil production from U.S. offshore wells or from development of oil shale reserves would have the opposite effect. Prices of coal liquids will be determined by the cost of coal (also rising), liquefaction plant investments and interest rates, and the operating costs for fuel production at commercial scale.

Principally through EPRI, utilities have funded and monitored several oil-from-coal projects in recent years. Furthermore, just this year an ad hoc group of utility executives probed the means (and, accordingly, their industry's role) for accelerating progress toward full-scale demonstration of coal liquefaction processes. Discussions with DOE centered on one process, solvent-refined coal (SRC-II), but the utility consensus is that other processes, at least H-Coal and Exxon Donor Solvent (EDS), should be carried forward as well. Foreseeably, these three processes can be commercialized to yield a total of 450,000 barrels a day by 1990 and 950,000 barrels a day by 1995.

The nature of coal liquids

Coal has yielded liquid fuels for the better part of a century. Kerosine, a petroleum product today, is still known in some markets as coal oil, thus revealing its origin. More widely recognized is the synthetic fuel produced in Germany during World War II. At that time, some two dozen plants combined to produce about 100,000 barrels a day—a small volume in today's terms but enough then to help fuel a nation blockaded from its overseas oil supply.

In making liquid fuels from coal, the problem has always been to augment the carbon atoms of the coal with hydrogen atoms. Carbon alone cannot be converted to a fluid, but hydrocarbon compounds can be produced as either gases or liquids. The major chemical process in use today is hydrogenation.

Hydrogenation can be clearly defined: "to combine or treat with or expose to hydrogen; esp., to add hydrogen to the molecule (of an unsaturated organic compound)." Coal liquefaction by hydrogenation is all of these. In simplest terms, pulverized coal, flowing in a solvent slurry, is heated and pumped into a pressurized reactor vessel together with a supply of hydrogen. The initial heat and pressure trigger a complex of chemical reactions that generate more heat and pressure and evolve a spectrum of liquid (and some gaseous) products. The process is aided, and in some respects controlled, by the use of chemical catalysts in the H-Coal and EDS schemes. Subsequent treatment of the process outflow yields a mix of different fuels and by-products, the latter including some hydrogen and all the solvent that is recycled to the reactor with a continuing flow of new coal.

Three contemporary processes

There have been fully a dozen approaches proposed for converting coal to liquid fuel form. Those with apparent potential as utility fuel sources have been evaluated by EPRI and its contractors. The clear survivors are SRC-II, H-Coal, and EDS. Methanol (often known as wood alcohol) can also be produced from coal, and the process is well advanced. However, methanol is inherently a higher-grade, more expensive fuel and therefore has a narrower prospect for use by utilities.

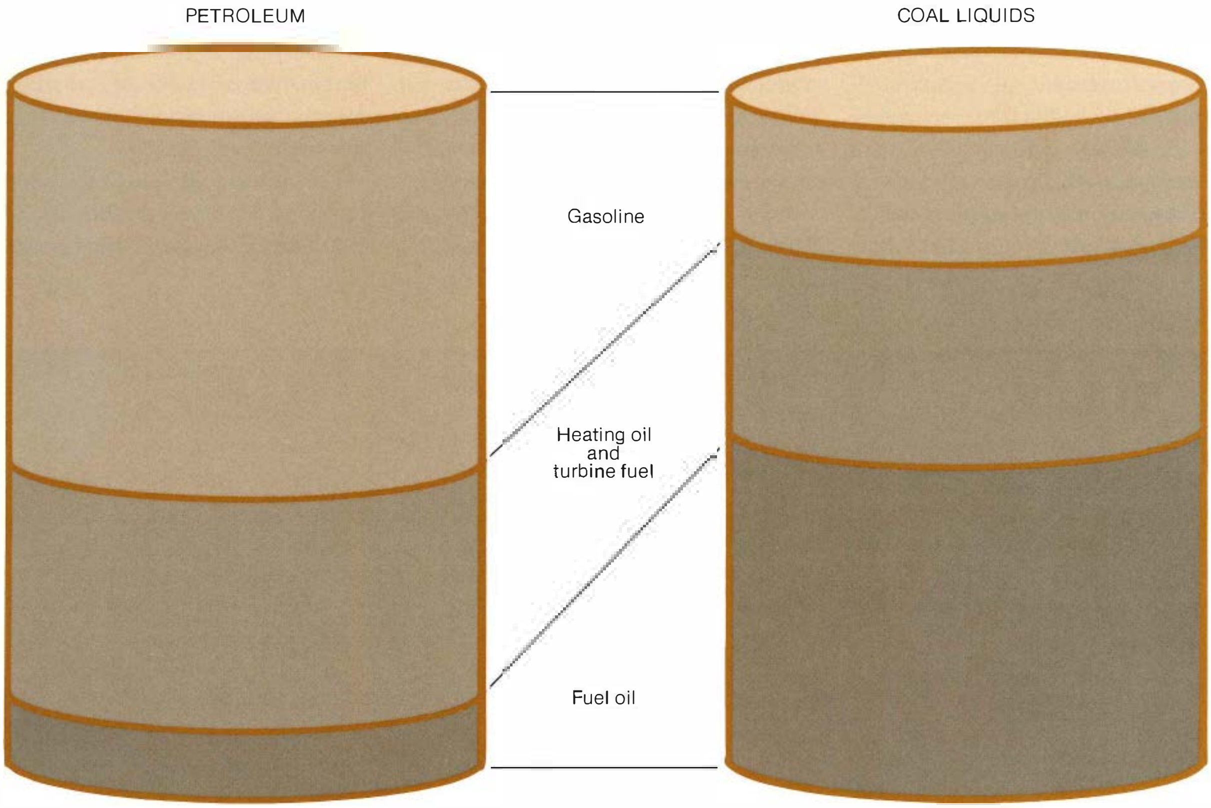
Broadly speaking, SRC-II, H-Coal, and EDS enjoy the same technical status today. Their feedstock conversion performance is the same: about 2.5–3.0 barrels of liquid fuel per ton of coal. And their conversion process severities —reaction time, pressure, and temperature—lie in a fairly narrow range: 15–60 minutes, 13.8–20.7 MPa (2000–3000 psi), and 400–460°C (750–860°F). The problems and risks to be faced in their future development, though different in kind, are comparable in degree. As a result, production potentials by 1990 for SRC-II, H-Coal, and EDS are also roughly comparable, judged by EPRI to be about 200,000, 150,000, and 100,000 barrels a day, respectively, from an industrial base that could reasonably be established by that time.

SRC-II This process has origins in Germany some 50 years ago, but it first came under U.S. scrutiny for liquid fuel production in the early 1960s. Research since then has explored its potential for yielding clean fuels in both solid (SRC-I) and liquid (SRC-II) forms.

In recent years, SRC-II development has largely been done by Gulf Mineral Resources Co. (a Gulf Oil Corp. subsidiary) with funding of some $100 million, primarily from DOE. EPRI has monitored progress, but its SRC support funds have been used to further the research on SRC-I (the solid form) spearheaded by Southern Company Services, Inc.

The SRC-II process involves a single reactor and does not employ a catalyst. It is the most advanced in terms of physical scale—a DOE pilot plant at Tacoma, Washington, has operated intermittently since July 1977 at 30 tons of coal a day (about 75 barrels of product daily). Earlier experiments were at bench scale (100 pounds a day) and in a process development unit (1 ton a day).

Because of the experience at Tacoma, SRC-II can probably be advanced to full-scale demonstration one or two years sooner than H-Coal or EDS, although there is some technical risk in



Both petroleum and coal liquids can be refined to produce different fuel grades, or cuts, for a variety of uses. Compared with petroleum, only minimal refining of coal liquids is required to produce turbine fuel and fuel oil suitable for oil-fired utility power plants.

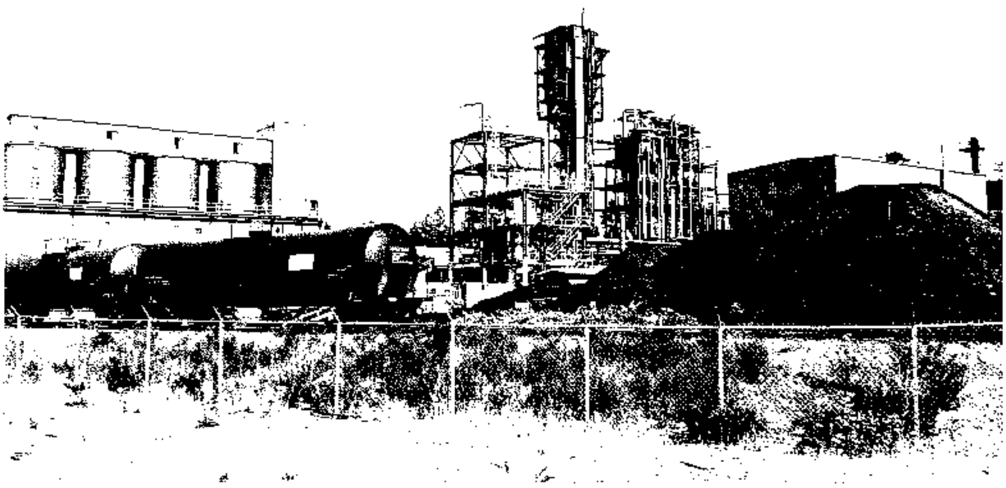
the single step-up from 30 tons a day. This acceleration is attractive to Gulf, DOE, and the electric utilities. In fact, Gulf has recently been awarded a DOE contract for the preliminary design of a 6000-ton-a-day plant that is planned to be operational in 1983. Through construction and startup, this plant is estimated to cost $700 million (in current dollars), and it will yield about 20,000 barrels a day of coal liquids. EPRI reviewers of liquefaction development believe the timetable to be optimistic by about one year because of the startup difficulties typically encountered with such a change in scale.

H-Coal Hydrocarbon Research, Inc., is the developer of this process, which has been under study, design, and test for 15 years. Ashland Oil, Inc., has taken an active role in a current $250 million development project that is also supported by DOE, EPRI, and several energy companies: Amoco Oil Co., Conoco Coal Development Co., Mobil Oil Co., and Standard Oil Co. of Indiana. EPRI's authorized H-Coal funding is $12.5 million.

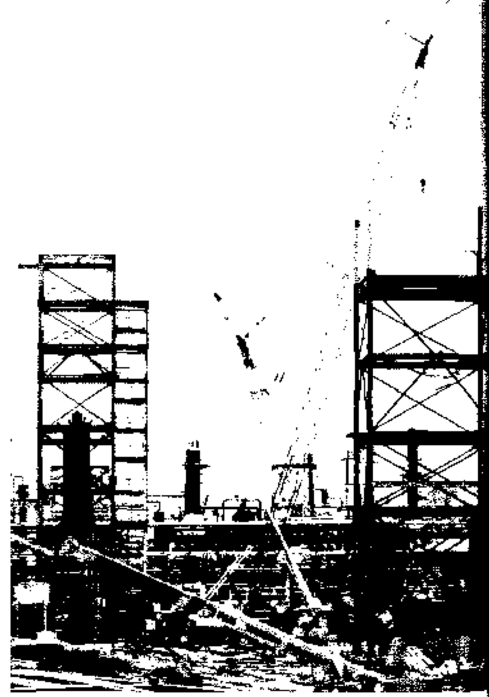
Like SRC-II, the H-Coal process employs a single pressurized reactor for the coal and hydrogen. But in this case, a catalyst (cobalt molybdate on alumina) is added, and the conversion reactions are further enhanced by fluidizing the constituents—injecting the gaseous hydrogen and the solvent-slurried coal under pressure at the bottom of the reactor, thus creating a highly turbulent suspension in which thorough mixing with the catalyst occurs. The advantage of this technique is uniformity of temperature with consequent predictability and the potential for close process control.

H-Coal liquids have been produced at bench scale (50–100 pounds a day) and in an integrated process development unit (1–3 tons a day), using a wide variety of coals, including samples from Germany and Australia. A 250–600-ton-a-day H-Coal pilot plant is now being built at Catlettsburg, Kentucky, at a construction cost of $100 million. It is scheduled to begin operations in the summer of 1979, producing 750–1800 barrels of liquid fuels a day. An important feature of its design is the incorporation of commercially available equipment wherever possible.

Hydrocarbon Research, Inc., has a record of success in commercializing new processes, and its principal associate



Coal pile and tank cars on a rail siding at Tacoma, Washington, symbolize the conversion of solid to liquid fuels in the 75-barrel-a-day SRC-II pilot plant operated for DOE by Gulf Mineral Resources Co.



Coal bins and cranes at Catlettsburg, Kentucky, mark construction of an H-Coal pilot plant for Ashland Oil Co. The 600-barrel-a-day facility is scheduled to begin operations in 1979.

in H-Coal, Ashland Oil, proposes that a 20,000-ton-a-day pioneer plant be built by 1985, capable of producing 50,000 barrels a day of coal liquids. Ashland's preliminary estimate puts the plant construction cost at $1.1 billion. EPRI believes these time and cost estimates to be somewhat optimistic.

EDS Developed by Exxon Research and Engineering Co., this process has drawn support also from DOE, EPRI, The Carter Oil Co., Phillips Petroleum Co., Atlantic Richfield Co., and this year from the Japan Coal Liquefaction Development Co., Ltd. EPRI's authorized contribution to EDS is about $40 million.

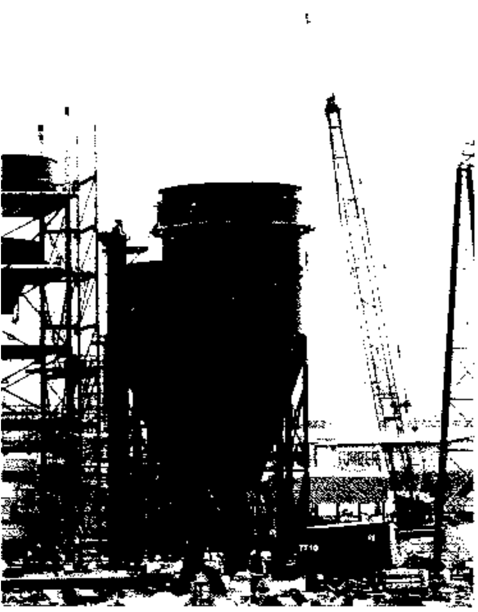
In contrast with SRC-II, which uses no catalyst, and H-Coal, where the catalyst contacts the coal directly, EDS employs its catalyst indirectly. The catalyst and solvent and perhaps half the process hydrogen are first combined in a catalytic reactor. The resulting hydrogen-rich solvent stream is then slurried with coal and enters the EDS process reactor, joined there by additional gaseous hydrogen. The solvent gives up its hydrogen in the conversion reaction, hence the term *donor solvent* associated with the Exxon scheme.

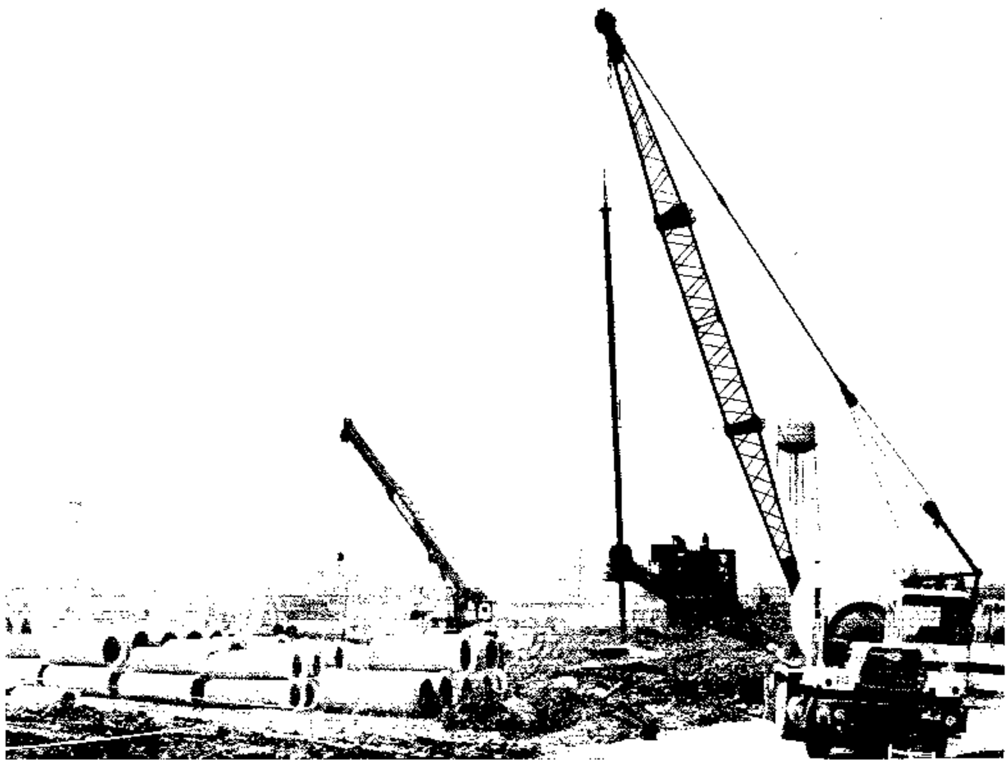
EDS development has paralleled that of H-Coal, through bench- and pilot-scale operations of similar size, 50–100 pounds a day and 1 ton a day, respectively. In May of this year construction started on a 250-ton-a-day pilot plant at Baytown, Texas, immediately adjacent to an Exxon refinery. The nearly $100 million facility—centerpiece of a $240 million cooperatively funded project—should produce about 700 barrels a day early in 1980. Like the new H-Coal pilot plant, it features commercial components as a means to accelerate proof of technological feasibility and provide firm engineering data.

Exxon foresees the next development step (after Baytown) to be a $1.4 billion pioneer plant that would process coal at a rate of about 25,000 tons a day in producing 60,000 barrels of liquid fuel. Such a plant could be built by 1987 or, EPRI estimates, accelerated to late 1985.

Choosing the next step

Traditionally, chemical process scale-up objectives are satisfied and verified in a sequence of steps characterized by their size: laboratory or bench-scale test, process development unit, pilot plant, and pioneer plant—the last being the proto-





Storm drains and other site preparation at Baytown,Texas, are the early work on Carter Oil Co.'s 700-barrel-a-day EDS pilot plant, with startup scheduled for 1980. Hydrogen supply and other services will be drawn from nearby Exxon refinery.

type of a full-size commercial facility. The pilot plant is the most significant step in this sequence because it is the scale at which technical risk, engineering, and cost bases are verified with commercial components for application at the stepped-up scale of a pioneer plant.

A lot of money is involved in today's coal liquefaction programs, money from the utility industry, the petroleum industry, and DOE. Multistep development may stretch the time schedule, and continued support of several alternatives adds to the cost. These points argue for focusing funds on one of the processes and somehow leapfrogging quickly to commercial scale to avoid inflationary cost escalation.

Of course, some scale-up efforts may not lead to commercial success; that is the way with technology development. And this argues for simultaneous development of all three liquefaction processes. The multistep and leapfrog approaches thus entail trade-offs of time, cost, and technical risk.

Pilot, pioneer, and demonstration

All three coal liquefaction processes will shortly (within two years) have pilot plants in operation. Two (H-Coal and EDS) will be large, as pilot plants go, with coal feed rates of at least 250 tons a day. The third (SRC-II) has already operated, but at the much smaller scale of 30 tons a day.

A pioneer plant can be justified even when it directly follows a process development unit if there are no unresolved large chemical interactions or changes in phase. Such is not the case with coal liquefaction, in the view of EPRI's research managers. The engineering basis simply has not been achieved. Knowledge of the fundamental chemistry is still imperfect, and it therefore isn't prudent to leapfrog the scale-up sequence for all three liquefaction options.

But now another scale-up step has entered the picture. It is called a demonstration plant, which is much larger than pilot scale but smaller than pioneer. This new idea in chemical process development is the basis of Gulf's recently begun SRC-II design effort.

Purposes and risks

Two routes to the commercialization of coal liquids are thus available. One relies on pilot operations; the other does not. Comparison of the purposes and characteristics of pilot and demonstration or pioneer plants illustrates the basis for choosing a development route. The notable implications favoring the pilot plant approach are these:

- It uses the smallest available equipment of authentic commercial size so as to minimize costs.
- It employs redundant equipment and subsystems to test alternative solutions for various process steps.
- It aims for integrated operation that fully defines the technical risk and cost of a subsequent pioneer plant.

According to this rationale, substituting a demonstration plant for a large pilot plant incurs the same technical risks at a less flexible and more costly scale, thereby increasing the risk of failure—at least within a given time frame.

The bold aim of the Gulf demonstration plant, of course, is to accelerate the schedule for production of near-commercial fuel volume from the SRC-II liquefaction process. Gulf's plant, at some 6000 tons of coal a day (or 20,000 barrels of output), represents a compromise in production between pilot- and pioneer-scale capacities but should permit confident expansion thereafter to the output of 100,000 barrels a day (or higher) from a full commercial plant comprising several parallel process "trains."

If the demonstration plant succeeds on its investment and time schedule (modifications being costly to both), then commercial production of coal liquids for the utility market will be accelerated. This is a substantial "if," and construction of the Gulf plant has heavy federal support because of the high risk.

Ensuring on-time production

Acceleration of the coal liquefaction program calls for accelerating all three process development schedules. In EPRI's judgment, Gulf's 20,000-barrel SRC-II demonstration may be achieved by 1984, slightly ahead of Ashland Oil's 50,000-barrel H-Coal pioneer plant late in 1985 and Exxon's 60,000-barrel EDS pioneer plant in the same year (which is two years sooner than Exxon's estimate). On an approximately equal basis for all three technologies, expansion to commercial status thereafter should yield daily capacities of 450,000 barrels by 1990 and 950,000 barrels by 1995.

Simultaneous development along these lines is, of course, a way of hedging our bets on coal liquefaction: there is a greater probability that at least one process will be fully successful on schedule. Other considerations also validate the approach. One is the ability to use many different coal feedstocks, processing them in the manner best suited to their properties to produce the most desirable mix of distillate and boiler fuel types. Another is the market value of having several competing suppliers. Still another is the wider sharing of the capital base required for development, including coal mine properties held by the liquefaction developers, which must also be brought into production. (A single 100,000-barrel-a-day liquefaction plant will require a coal input equivalent to the production of five mines, each yielding 2 million tons annually.)

Do these considerations ensure total success? Of course not. But the combination of pilot plants (to prove integrated technology at the smallest authentic scale) with a demonstration plant (to approach commercial scale more rapidly with one of the processes) represents a good compromise in reconciling the risks of time and money needed to scale up coal liquids.

HOW WELL DOES LIQUID COAL BURN?

Coal liquefaction processes themselves are the subject of this article—their status today and the avenues and prospects for bringing any or all of them to commercial reality. But making a clean-burning fuel in a reliable and economical manner isn't the same as using it in a power plant reliably and economically.

If there is one generic problem common to SRC-II, H-Coal, and EDS, it is the lack of thorough, uniform, and authoritative data on the handling, storage, and (especially) combustion characteristics of coal liquids beneath utility steam boilers or in gas turbine combustors. Coal is a widely variable feedstock, depending on its geographic source, and a thoroughly representative range of types has not yet been put through all the coal liquefaction processes. The spectrum of fuel samples is therefore limited. Some combustion tests have been made at laboratory scale, but much field testing will be needed to ensure that oil-fueled turbines and boilers can use the coal-derived distillates and heavier fuel grades with only modest equipment changes—or, better yet, with none at all.

A large (4500-barrel) sample of SRC-II fuel was to have been tested last month in a Consolidated Edison boiler, and even larger samples of H-Coal and EDS pilot-plant fuel production will be available for test in 1979 and 1980. Open issues include:

- The fate of fuel-bound nitrogen
- Combustion stability
- Stack emissions
- Effects of trace elements on turbine blading
- Storage stability
- Handling characteristics

Resolution of these fuel utilization issues is needed to confirm or modify present practices. For coal liquids to be used in firing combustion turbines, it is likely that some secondary upgrading will be necessary in meeting environmental standards. Laboratory tests indicate that SRC-II, H-Coal, and EDS fuels can be upgraded. Large samples for large-scale field tests are thus an important objective of the pilot-plant programs in coal liquefaction.

Managing Corrosion Control

by Thomas O. Passell

Pioneering a new style of industrywide technical exchange, the Corrosion Advisory Committee helps to coordinate and guide a large variety of projects that will accelerate practical application of R&D results.

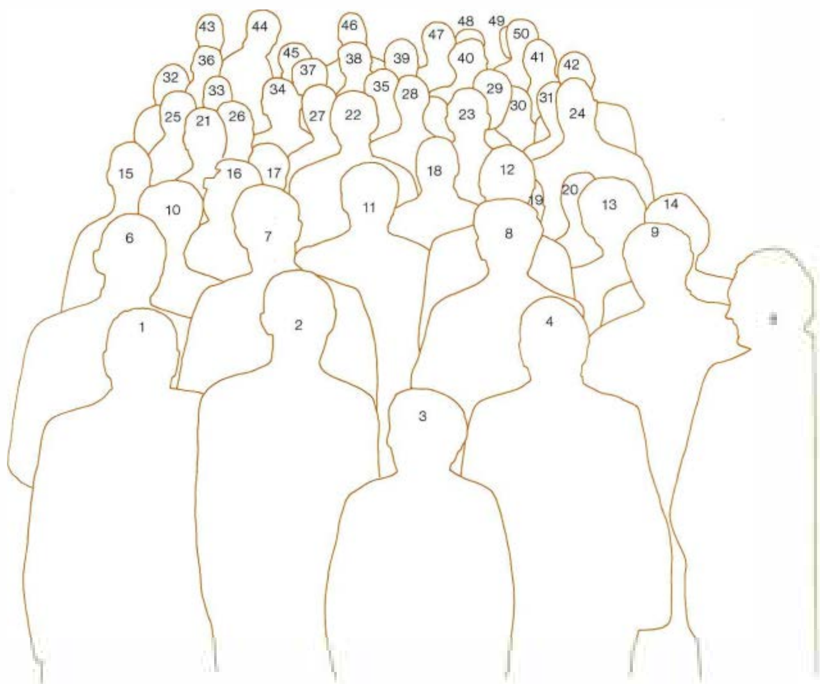
Engineers and scientists constituting the EPRI Corrosion Advisory Committee (CAC) have met quarterly since January 1975 to discuss possible remedies to a continuing series of puzzles. These puzzles necessitate scientific detective work to find the sources of the different types of corrosion that may attack components of power plants—sometimes causing costly outages and thus requiring vigilance in inspection and maintenance.

The objective of CAC, according to Edwin L. Zebroski, director of the Systems and Materials Department in EPRI's Nuclear Power Division, is "to guide the efforts of the power industry in solving a number of costly operating problems with major power plant components—problems caused by subtle types of corrosion. Ordinary gross corrosion—loss of metal by oxidation—is now almost completely controlled in most nuclear units and in all but a few places in fossil-fueled units. However *localized* corrosion, or cracks that are corrosion-initiated, can result from locally aggressive conditions even when overall corrosion is negligible.

"Corrosion effects have long been known to be one of the major root causes of plant outage and of inspection, repair, and replacement requirements. With the increasing cost of replacement power, the incentives for controlling and preventing localized corrosion are nearly ten times higher than they were just five years ago.

"For example, tiny corrosion-induced cracks, so narrow they can hardly be seen except under a microscope, have caused days or weeks of added outage time for a number of billion-dollar power plants, outage that can cost as much as $300,000 per day of downtime."

A recent study by the National Bureau of Standards estimates that total costs of metallic corrosion in the United States amounted to more than 4% of the total



1. Jerome Kruger, National Bureau of Standards. **2.** James Begley, Ohio State University. **3.** Thomas McNary, Babcock & Wilcox Co. **4.** Joseph Danko, General Electric Co. **5.** James Cobble, San Diego State University. **6.** George Taylor, Atomic Energy of Canada Limited. **7.** Frederick Pocock, Babcock & Wilcox Co. **8.** Warren Berry, Battelle, Columbus Laboratories. **9.** Thomas Passell, EPRI. **10.** Paul Bryant, Combustion Engineering, Inc. **11.** Lawrence Sarver, Babcock & Wilcox Co. **12.** Rolf Riess, Kraftwerk Union. **13.** Heinz Schroeder, Vereinigung der Grosskraftwerkbetreiber E.V. **14.** Geoffrey Egan, Failure Analysis Associates. **15.** Jeffrey Gorman, MPR Associates, Inc. **16.** Louis Martel, EPRI. **17.** Jack De Van, Oak Ridge National Laboratory. **18.** Edwin Zebroski, EPRI. **19.** William Cahill, Consolidated Edison Co. of New York, Inc. **20.** Samuel Rothstein, Consolidated Edison Co. of New York, Inc. **21.** Douglas Fletcher, Westinghouse Electric Corp., R&D Center. **22.** Richard Garnsey, Central Electricity Generating Board. **23.** Richard Weeks, Argonne National Laboratory. **24.** Richard Smith, EPRI. **25.** Clarence Hultman, Standardized Nuclear Unit Power Plant Syndicate. **26.** Ronald Latanision, Massachusetts Institute of Technology. **27.** Wesley Pearl, Nuclear Water & Waste Technology, Inc. **28.** Walter Riedel, Baltimore Gas and Electric Co. **29.** Roger Staehle, Ohio State University. **30.** Robert Rentler, Combustion Engineering, Inc. **31.** Richard Begley, Westinghouse Electric Corp., R&D Center. **32.** Gerald Sabian, General Electric Co., Knolls Atomic Power Laboratory. **33.** Takashi Kojima, Tokyo Electric Power Co. **34.** Marcel Cordovi, The International Nickel Co. **35.** Carl Cain, Tennessee Valley Authority. **36.** Tatsuo Kondo, Japan Atomic Energy Research Institute. **37.** Tsuneo Futami, Tokyo Electric Power Co. **38.** Paul Cohen, Private Consultant. **39.** Richard White, Bechtel Corp. **40.** Robert Jaffee, EPRI. **41.** Jesse Lumsden, Rockwell International Corp. **42.** Jeffrey Carter, Portland General Electric Co. **43.** Philippe Berge, Electricité de France. **44.** Rodney Hanneman, General Electric Co. **45.** William Singley, Westinghouse Electric Corp., R&D Center. **46.** John Wooten, Westinghouse Electric Corp., R&D Center. **47.** Jay Schultz, The International Nickel Co. **48.** John Esposito, Westinghouse Electric Corp., R&D Center. **49.** James Vaughn, Department of Energy. **50.** Bo Rosborg, Studsvik Ab Atomenergi.

Thomas Passell, cochairman of the Corrosion Advisory Committee, is project manager for corrosion technology in EPRI's Nuclear Power Division.

GNP, or about $70 billion in 1975. Of this, approximately $10 billion was identified as being preventable in principle with present technical knowledge. And a large part of the additional $60 billion could be prevented with methods that appear practical in principle but are still to be developed.

CAC helps to direct the attention of leading U.S. and overseas corrosion technologists to practical operating problems, with primary attention to infrequent but high-consequence occurrences in power plants. This helps to focus EPRI's corrosion research, which is believed to be one of the largest coordinated efforts in the world on practical corrosion prevention.

The basic priorities and key practical issues are defined by the EPRI utility advisory structure working with EPRI staff. The Nuclear Systems and Materials Task Force and its Materials and Corrosion Subcommittee provide current plant observations and experience and help define practical directions for application of research results. CAC supplements the EPRI utility committees by helping to decide which of the large number of possible research and testing methods are most likely to provide results that can meet the practical needs of utilities.

Origin of CAC

The story of CAC is interesting for what it tells about how EPRI has been able to marshal and coordinate industrywide research in a problem area vitally important to electric utilities.

CAC was organized early in 1975 by Zebroski, who enlisted Roger Staehle of Ohio State University, one of the best-known researchers and consultants in corrosion metallurgy, as chairman.

As Staehle says, "To have the best chances of really solving the practical problems at the plant level as well as understanding the basic causative mechanisms, we needed to collect the entire cast of actors in this drama in one room—key technical people representing the reactor manufacturers, architect-engineers, utilities, metal producers, universities, research institutes, and government laboratories where corrosion research is pursued. Further, we had to have a style for the meetings that would make them worthwhile to the participants, all of whom are extremely busy people."

As corrosion does not single out nuclear plants, the Fossil Fuel and Advanced Systems Division of EPRI has also contributed to the work of CAC. There is considerable commonality in some types of corrosion found in nuclear and in fossil units, for example, that occurring in turbine disks and blades.

The agenda of CAC has often included review of work and observations related to fossil-fired power plants. Many of the discussions are equally applicable to fossil, nuclear, and advanced technology plants. So far, the number and size of projects have been larger on nuclear units where the cost impacts (and incentives) are greater than for fossil units. The reason for this is that nuclear plants have the advantage of the lowest incremental generating costs of existing options in most areas of the country. Conversely, nuclear plant outages have larger financial effects on utilities and ratepayers, and plant maintenance and repair is usually more costly. Many corrosion-related issues require sensitive inspection and control to meet stringent regulatory requirements, a factor with more effect on nuclear than on other power sources.

Structure of CAC

Members nominally serve three-year terms. The principal requirement is that they be active and productive in research, testing, or applying and observing the effectiveness of remedies for important corrosion problems. According to Staehle, "Participation with solid information is the key to membership in CAC. If a member contributes a presentation with extensive data and results, or spearheads enlightened discussion, or is willing to take such responsibilities in one of our subcommittee meetings, the prime requirements for membership have been fulfilled." There is a certain excitement created when someone describes the latest results from investigations of major corrosion concerns or tests of remedies. This brings the members to each meeting with anticipation.

As interest has grown, the membership has increased from 18 persons at the early meetings to about 40 regular participants at the most recent one, with 20 additional persons invited to contribute presentations.

Why another committee?

Prior to the founding of CAC there were already several corrosion committees within such organizations as the National Association of Corrosion Engineers (NACE), American Society of Mechanical Engineers (ASME), American Society for Testing and Materials (ASTM), American Society for Metals (ASM), the Edison Electric Institute (EEI) Prime Movers Committee and several subcommittees, and the Metal Properties Council (MPC). Why would anyone wish to form yet another committee dealing with similar issues?

The established committees cover a wide spectrum of both basic and applied problems, but it was felt desirable to have a group focused more sharply on guiding large and timely applied research efforts useful to the power industry.

Liaison with these committees is convenient as many of their members (and often the chairman) are also members of CAC. Coordination of related activities in EPRI's Nuclear Power Division and Fossil Fuel and Advanced Systems Division is also facilitated by participation in the CAC. Several utility people, chosen for their expertise and their membership on the Systems and Materials Task Force or the Steam Generator Advisory Committee, are also members of CAC.

Why at EPRI?

There were at least two reasons why EPRI took the initiative in establishing CAC. First, there was a need to shorten the turnaround time between knowing what to do and doing it. In existing committees, reaction time was slow because corrosion observations and data were written up for publication in professional journals in the traditional way—a process that may take many months.

The members of CAC, while technical experts in their own right, also usually have research leadership responsibilities. Thus CAC affords quick communication of research results and key observations from operating plants on new problems, new solutions, or new results in testing proposed remedies. It provides for their timely airing and evaluation before a highly competent group of specialists in the technology.

Second, through CAC, the industry obtains the benefits of expert advice and a variety of analyses of current results in guiding its own work on projects to mitigate corrosion damage in power plants.

Proprietary concerns

One of the issues perceived in organizing CAC was the difficulty of bridging proprietary concerns that might at times inhibit technical exchange among competing organizations. This has been handled formally by observing the "Kennedy rules" for meetings including competitors. These rules require a neutral party (in this case EPRI) to set the agenda, chair the meetings, and prepare minutes and summaries.

If the power systems of only one or two system or component suppliers had problems, this might indeed have been a difficult obstacle. However, most corrosion-related issues appear to be generic, both in the United States and overseas. Statistically, all suppliers have experienced enough problems to benefit by generic research, and of course utilities and ratepayers carry the main financial burden of consequential costs. For nuclear units, the regulatory requirement of full disclosure for safety reasons has greatly reduced the tendency to defer and deemphasize technical disclosure of problems and remedies under the guise of commercial secrecy.

Most important, it is now widely recognized that corrosion problems are often system operating problems, which means that they can rarely, if ever, be adequately covered by commercial warranties. For such issues it is a responsibility of the utility, acting in the public interest as well as its own, to get the best possible data and practical information that will enable it to operate in a manner that minimizes the consequences of corrosion effects.

Scope of CAC work

The earliest high-priority problems faced were with the cracking of type-304 stainless steel in the bypass lines in the primary coolant loop of General Electric Co. boiling water reactor (BWR) systems. These problems even attracted attention in congressional hearings in 1975. As time went on, the wastage and the denting of tubes in pressurized water reactor (PWR) steam generators manufactured by Westinghouse Electric Corp. and Combustion Engineering, Inc., became a major topic of discussion. Some steam generators of Babcock & Wilcox Co. have also exhibited tube damage effects that are peculiar to the once-through design. Turbine disk cracking problems have been observed on the turbines of most major vendors.

Looking back over the four-year history of CAC, all the suppliers have had roughly equal time on the hot seat during the many issues considered. Every participant recognizes that suppliers of major power plant equipment and the utilities are in a war against a common enemy—corrosion damage, which hurts plant productivity and usually results in use of more oil.

To encourage free discussion, some concessions are made to commercial and licensing sensitivities. Distribution of preliminary and as yet incomplete or uncertain information is restricted. Minutes and summaries are produced and distributed to the membership and to interested utilities for their review but not for quotation or citation. If a utility wishes to use some of the information, for example in a licensing submission, the specific data and release must be obtained from the originator of the data.

Foreign participation

As EPRI represents U.S. utilities, the membership of CAC is predominantly from the United States. However, as corrosion is no respecter of national boundaries and the power industry and corrosion research are international, it is appropriate to have representation from overseas organizations that do extensive work on corrosion problems.

Other countries represented in the initial membership were Switzerland, France, Japan, and Canada. Later, representatives from Sweden and the United Kingdom were added, and recently the Federal Republic of Germany has been represented by the chairman of a similar utility industry committee in Germany. Belgium has been represented on at least two subcommittees.

Attempts are made to invite presentations of related work from major world organizations. U.S. government work is represented by research people from DOE, NRC, Bureau of Standards, nuclear navy, and national laboratories.

Topics considered

From its inception, EPRI programs and CAC have concentrated on those questions that have the largest actual or potential consequences for plant availability. For example, why are cracks appearing with rare but annoying frequency in the rotors and blade attachment regions of large steam turbines? (Certain steam-electric plants, both nuclear and fossil-fired, show this.) What is causing the infrequent but troublesome cracking (and very rarely, actual leaks) of certain pipes in BWRs? What are the factors controlling the rate of corrosion damage to steam generators in some PWR plants, some of which may require replacement?

BWR pipe cracking was the first major issue addressed by CAC. Although General Electric Co., the sole BWR supplier in the United States, had started an intensive study of this issue, many practical questions remained unanswered. EPRI staff and utility committees initiated a number of projects oriented to pipe cracking. Where there seemed to be a bewildering number of technical possibilities to choose among, EPRI was guided by discussions in CAC. This buildup phase lasted through 1975 and 1976.

During 1975 the PWR problems were visible but not dominant. For example, during this period the changeover to all-volatile water treatment on the secondary side (the steam generator–turbine–condenser portion) of the PWR plant was being implemented by Westinghouse, the largest manufacturer of PWRs. This changeover from phosphate treatment was expected to cure most of the steam generator tube wastage problems (localized metal loss and pitting) that have been observed with phosphate treatment. In that respect it was successful.

However, in 1976 a new phenomenon known as steam generator tube denting began to be observed. This first showed up in plants that had a history of many months of phosphate treatment before the switch to all-volatile treatment. Subsequently, in 1977, some plants that had used only all-volatile treatment also started to exhibit denting. Also for the first time, primary-to-secondary leaks began showing up in PWR plants with once-through steam generators. Measures to control the ramifications of all these issues are currently being tested. The evident need for a much larger rate of effort on PWR steam generators than could be funded by EPRI led to the formation of the Steam Generator Owners Group, a decision strongly supported by the Systems and Materials Task Force and its Steam Generator Subcommittee. This group of utilities, including several overseas utilities, has pledged more than $30 million for a large-scale attack on the PWR problem, which is managed by EPRI.

Finally, the issues pertaining to the cracking of low-alloy steels in large steam turbines became of interest to CAC after a pair of rotors had to be replaced in two similar modern PWR units and disk cracking began to be found in nuclear as well as fossil turbines.

There are other issues of long-term concern, however, that have not yet been addressed. For example, no appreciable effort has been expended thus far on corrosion aspects of alternative nuclear or fossil technologies.

Completing the loop

In addition to its direct value in advising EPRI staff and utilities, one of the main accomplishments of CAC is that it brought together an advisory group composed of some of the world's best corrosion specialists, those having the precise background and experience to provide technical insights to key problems. In one forum CAC covers three functions that are often not well connected in either applied or fundamental R&D:

- The direct observation of field problems and of the effectiveness of attempted remedies
- The formulation and reporting of research efforts to diagnose and remedy practical problems and their root causes
- The rapid interpretation and communication of both field data and laboratory test results to key people in utilities and vendors who are in a position to make practical decisions required to implement remedies or preventive measures

Before CAC, when corrosion-induced damage was found that could have serious consequences to plant operation, the utility, the vendor or vendors most directly involved, and consultants usually met and tried to pinpoint the cause or combination of causes. This group in turn presented to utility management its best estimate of the nature of the problem, as well as suggested courses of action. While some of this information was eventually published, usually only a small fraction reached the technical community at large. An oversimplified view of causes and remedies had often circulated. Full analysis of alternatives was sometimes inhibited at this stage by a vendor's proprietary position and defensiveness regarding possible liabilities for units still under warranty.

This approach, while sometimes successful, has obvious disadvantages when the actual problem is complex, the first few remedies do not work, or the consequences are larger than first estimated. Also, relevant observations from other plants or from related research efforts may not be fully used. Thus a lower rate of problem-solving—and occasional repetition of mistakes—can occur.

An advantage of the approach that involves CAC as well as EPRI utility committees is that it provides a broad and timely peer review process at the highest levels of technical expertise available, with rapid feedback from plant and test experiences. A broad spectrum of basic information on corrosion-related damage events in nuclear plants of all vendors in many countries can be considered on a timely basis. Subsequently, proposed remedies of a wide variety can be examined in greater depth and the more promising ones rapidly subjected to practical testing.

An additional advantage is the speed with which this knowledge is distributed to many of those most in need of it. While these are qualitative benefits on specific problems, such as those mentioned above, they can be translated into large economic benefits to utilities and their ratepayers.

A side benefit of this process is a reduction of the duplicate efforts that could occur if each utility owning one of the several designs of reactors in current use had to solve by itself the generic as well as the unique aspects of each problem.

The incentives for this type of interaction between research and rapid application of results of plant operations continue to increase as the large financial leverage of increased reliability of baseload plants becomes more widely recognized. As the cost of new baseload plants has increased and the incremental cost of replacement power has escalated, the payoff has multiplied for finding and implementing short-term fixes and midterm remedies. With the coordinated efforts possible in such a joint enterprise, long-term solutions (including basic specifications for design, materials, and process improvements) will be based on statistically reliable data rather than on a few scattered tests and inspired guesses.

Future plans

CAC will continue to hold semiannual plenary meetings at which the latest work observations on major issues are presented. In addition, CAC will hold special subcommittee meetings on matters of pressing interest, such as the chemical cleaning of steam generators to arrest denting, improving the integrity of condensers to avoid leakage, water treatment, and the corrosion problems that may be initiated during the construction phase of nuclear plants. CAC members and EPRI staff have also run a number of workshops and seminars for utility personnel and for consultants and architect-engineers.

Some areas will probably remain outside the purview of CAC. For example, pressure vessel safety issues related to fatigue crack propagation or radiation effects are covered by a related technical advisory committee, the Pressure Vessel Study Group. Similarly, very little has been said about the corrosion aspects of nuclear fuel, which also is covered by other active advisory groups.

Nevertheless, the discussion in CAC often expands, spilling over into new issues. For example, the problem of the decontamination of primary loops in nuclear reactors has been reviewed from time to time as it is a significant determinant of the ease of access to make repairs.

Also, the issues of nondestructive examination (NDE) have been intensively discussed in CAC as this is the key to detection and eventual repair of such damage. However, the theory of NDE and development of devices is covered by the NDE subcommittee of the Nuclear Systems and Materials Task Force.

CAC will continue its efforts to accelerate the process of resolving utility corrosion concerns. The aim is to make itself unnecessary eventually by making corrosion problems a matter of anticipation and prevention rather than a matter of response to emergencies.

Don McCammond: Renewing Confidence

The natural community of interest between utilities and their customers—once widely accepted, now questioned—needs to be rekindled by the utilities through candid, assertive communication.

Don McCammond, public relations vice president of Virginia Electric and Power Co. (Vepco), leaned back in his office chair and told a favorite anecdote that illustrates how not to practice public relations.

"A newly rich, social-climbing lady hired a genealogist to trace her family tree," McCammond relates in a Boston accent softened by nearly 25 years in Virginia. "The genealogist's research turned up a grandfather who had been electrocuted in a state penitentiary for a major crime. 'I won't have that showing on my pedigree,' the irate lady exclaimed. 'Get rid of it, hide it.' The genealogist protested, but the lady persisted. Stymied, he consulted a friend who was a public relations expert. After mulling over the problem, the public relations counsel advised, 'It's really quite simple. Just tell the truth. You can say that the grandfather occupied the chair of applied electricity at one of the best-known institutions in the state. And that he died in harness.'" McCammond leaned forward and made the point, "We have come a long way from that."

A former national chairman and president of the Public Relations Society of America and a past president of the Old Dominion (Virginia) and New England chapters of PRSA, McCammond feels strongly that "public relations is not a blue-sky operation with a bagful of gimmicks, a skein of evasion, a gaggle of gossip, or a tissue of lies. Any public relations operation based on such a philosophy won't last long with the discerning men and women who control and manage the channels of communications. Or with anyone else whose opinion may be important."

He says that "too often a couple of public relations axioms seem to get lost under the pressures on all of us today. One is that when there is bad news, get it out and get it behind you. The second is that performance precedes publicity, both good and bad publicity. Behavior itself is a form of communications."

McCammond, who is chairman of EPRI's Communications Committee, believes that, "Business and the public should be allies, not adversaries." And he points out, "Our constituents want to know why problems exist and how we propose to solve them. Strengthened communications programs that explain our mutual problems and their impact and possible solutions are gaining ground with the public. But such programs must be backed by solid performance."

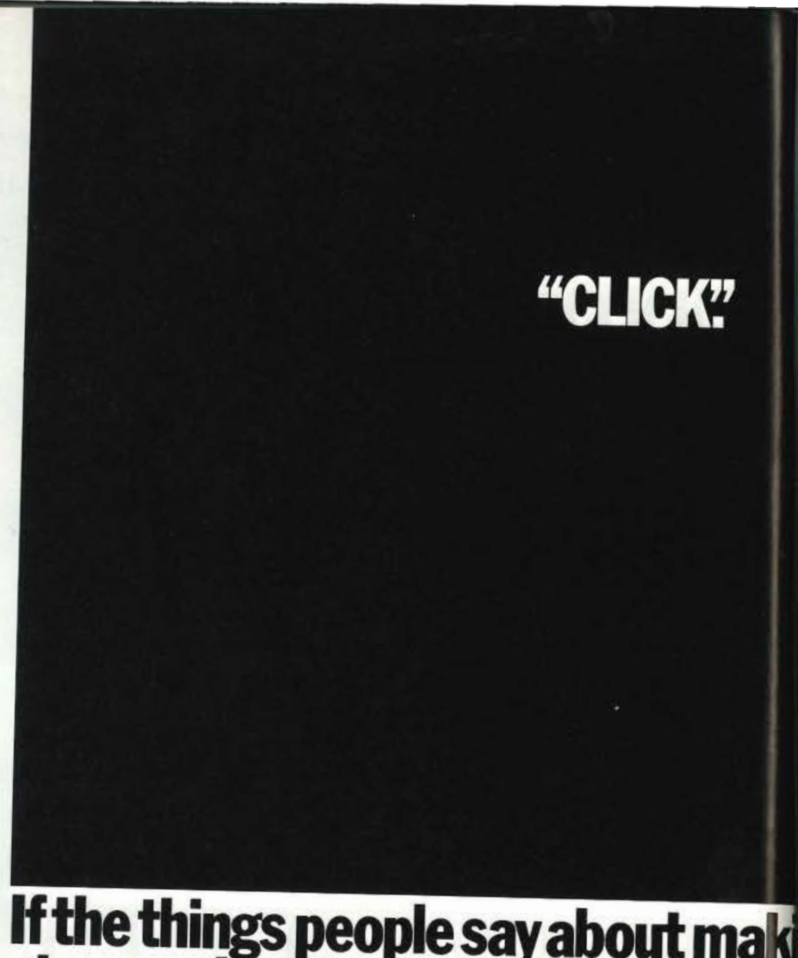
Faced with today's demands to preserve the environment at any cost, to hold the line on utility rates, with the determined opposition to nuclear power and the general groundswell of consumerism, McCammond and his public relations staff of 30 at Vepco have more than ample opportunity to apply their expertise and high professional standards. McCammond recently shared some of his experience and views with the *Journal* at an informal interview in his office and the cafeteria in Vepco's headquarters in Richmond.

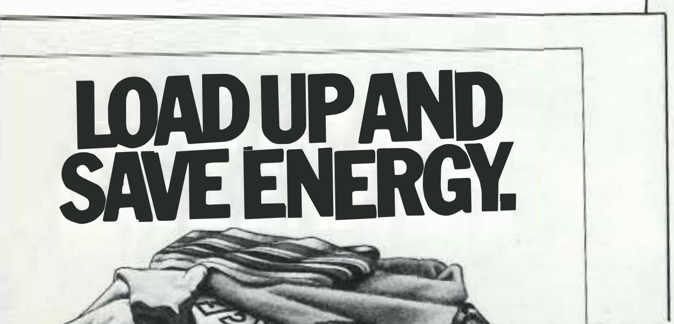
Telling the utilities' story

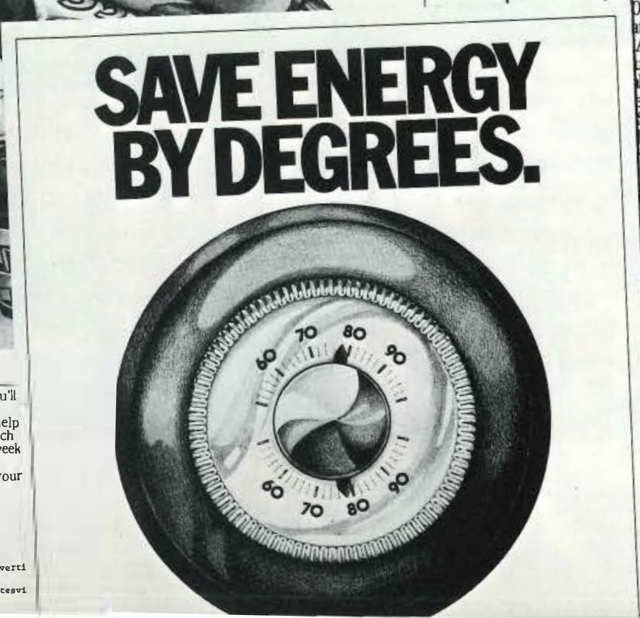
A native Bostonian, McCammond is a lawyer and a former staff writer for *The Christian Science Monitor*. He held key public relations posts with Monsanto Co., Reynolds Metals Co., and American Can Co. before joining Vepco in 1970 as vice president and director of the utility's public relations activities. He also served in the Pentagon as the executive assistant to the Assistant Secretary of Defense for Legislative and Public Affairs.

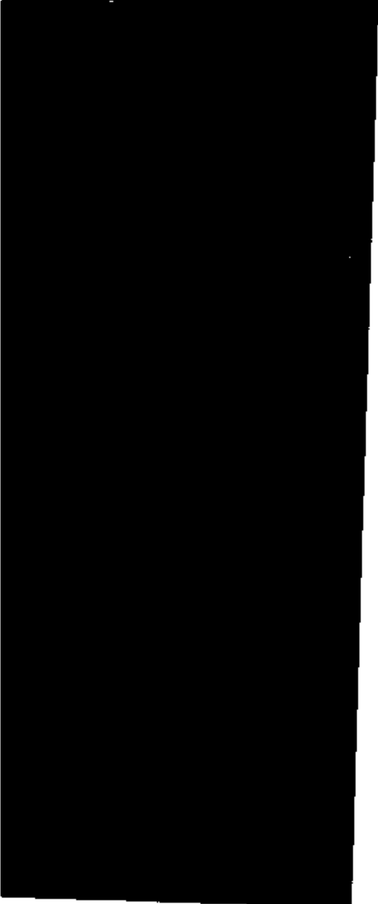
Vepco is an investor-owned utility that supplies electric power to most of Virginia, parts of North Carolina and West Virginia, and natural gas to the Norfolk–Newport News area, north to Williamsburg. The company recorded a 23% increase in operating revenues in 1977 over the previous year, while power output was up 5% and new winter and summer peaks were reached. Over 40,000 new residential electric customers were added. Significantly, operating and maintenance costs in 1977 rose a sharp 31% over 1976, the major factor being increased fuel costs. The cost of fuel in 1977

Don McCammond and his staff, working with a Richmond advertising agency, have created an imaginative, candid information campaign to tell the public the facts about electric power supply and demand and to encourage energy conservation. This sampling of Vepco newspaper ads, whose theme is "America is a powerful idea. Let's keep it that way," illustrates the bold, direct approach. McCammond (seated at his desk) discusses the campaign with his department heads: (from left) Hank Holloway, advertising and employee communications; Bill Crump, community affairs; and Bruce Miller, public relations.









electricity were nd walk home.

le. Jobs and lifestyles would be at stake. And nds who have not yet attained a normal standliving would not have a chance.

hat's the solution to keeping the lights on— today but also ten years from now? We believe ear, coal, hydro-pumped storage and more ation. But it won't be cheap. With the racing we have all faced in the Seventies, there is no eturn to the cheap energy of the Sixties.

nder our franchise, we have no choice. We must y demand you place on us at any time, in any Your peak demand is still going up—12 per her than last year and more than double what n years ago. Despite all efforts at conservation. we must plan ahead, regardless of inflation, ry delays, or criticism from those who consider gy crisis no more than an opportune target. ese are tough decisions, but someone must em. They won't be made by turning out the d walking away.

Vepco

America is a powerful idea. Let's keep it that way.

frightening about nuclear ng the 1980's without it. nergy, Virginia won't have 1985. It's as simple...

public. Not one. And it's technically and physically impossible for a nuclear plant to explode like a nuclear bomb.

in the 1980's, we'll need nuclear power balanced generation...

our customers crease prices?

Now more than ever yo a crash course in saving Feel free to use our n

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AIR CONDITIONER:	AIR CONDITIONER THERMOSTAT:	STORM WINDOWS:	AIR CONDITIONER: If furniture	AIR CO 78

accounted for nearly 70% of Vepco's total operating and maintenance expenses.

McCammond finds that it is hard to convince the public that utilities are dedicated to providing service at reasonable cost, even in the face of double-digit inflation and spiraling fuel costs and, he says, "even when we're the only industry I know of that promotes less use of its product." He calls attention to the fact that while the cost of living rose over 330% between 1940 and 1977, the average annual unit cost of electricity of Vepco's residential customers increased only 19%.

A booklet produced by McCammond's group gives some of the vital statistics that affect costs of generating and delivering electric power to Vepco's 1.2 million customers. Along with the figures just cited, the booklet shows that the average monthly residential bill (January 1978) for 1000 kilowatthours in 12 selected eastern cites was $41.82 in Richmond compared with a high of $82.67 and a low of $32.96 in the other cities. It also points out, "Vepco has taken a leadership role in the development of nuclear generation of electric power since the early 1960s," and that the company's two generating units at the Surry Nuclear Power Station, which began operation in 1973, "have saved customers the staggering sum of $375 million." (This figure represents what was saved by using nuclear power units and fuel instead of comparable coal or oil-fired plants.)

"Vepco Research Report," a pamphlet sent to all its customers, presents a brief, simply stated review of the realities of nuclear, hydroelectric, and geothermal power and of energy from waste. It states, "Vepco is taking a major step toward energy independence through its research program, dedicated to finding new and better ways of meeting the energy needs of tomorrow." It notes that Vepco has joined with other utilities in supporting EPRI, founded in 1974 for the same purpose.

McCammond has used the street-level window display space in Vepco's vintage 1913 headquarters building to tell some of the bread-and-butter aspects of the company's story. One exhibit, for instance, shows that the cost to the customer of electricity has followed a downward curve from 7¢/kWh in 1930 to about 3.5¢ in 1940 and to less than 2¢ in 1969. Since then, inflation and soaring fuel costs have driven the rate up to 4¢.

Need to reach customers

McCammond was asked where he worked by a woman at an Urban League meeting in Richmond. When he answered, "At the power company," she replied, "You poor man!" McCammond told her he felt good about his work and was in no need of sympathy; that the power company was providing a service the people wanted—and reliably. The woman said she knew that and was grateful and hoped the company would never let her down in service. She noted there are some people who single out the utilities as villains and added, "I don't like paying higher utility bills, but I'm paying more for everything these days." McCammond says he looks forward to the day when more people recognize, as the woman did, "that utility rates are not the only thing going up in price."

McCammond looks on 1970, the year he joined Vepco, as "the dividing line between the old and the new attitude toward power companies. Before 1970, a new transmission line or a distribution line was greeted with open arms because people welcomed the convenience this service brought. Today," he regrets to say, "people want the convenience but they don't want transmission or distribution lines crossing their property." And he adds, "The higher rates needed to recover the increased costs of operation since 1970 have become footballs for politicians to kick around."

McCammond says, "We have to rebuild those natural bridges to our customers that existed earlier. We need to remind people that we really are interested in them and in their dilemmas and problems. We just can't sit by our phones and wait for them to call. We have got to try to anticipate their problems. And we need to let our customers know that we do worry about rising costs and the impact this has on them." He adds, "We have to think of how we're going to keep operating in the future as more people move into our service area. And to do that, we have to plan at least 10 years ahead."

McCammond notes, "One of the main reasons the utilities got together to create EPRI was to come up with ways to use our existing equipment more efficiently and to develop sources of energy for the future that won't cost us an arm and a leg—to find practical, cost-realistic ways of providing energy in the future." He sees research and development as one of the strongest elements utilities now have, but they are not making much about it with the public. The fact that "the utility industry, unlike other industries, shares the fruits of its R&D so everyone may benefit is something we need to make known to the public," McCammond stresses. "Vepco shared its experience in developing the 500-kV transmission line and it was quickly picked up by other utilities," he recalls.

Promote R&D efforts

As a member of communications committees of the Edison Electric Institute and the Atomic Industrial Forum, as well as heading EPRI's communications panel, McCammond is in a good position to get an overview of and have some feeling for the general public relations approach of the industry. He is also aware of the public relations programs of other industry groups, such as the American Public Power Association, National Rural Electric Cooperative Association, and the National Association of Regulatory Utility Commissioners.

McCammond is convinced that "the job of telling the industry's story is mainly the responsibility of individual utilities, adapting and using materials provided by the various industry associations." And he repeats that the utilities "especially need to tell the R&D story to the public, who knows nothing about the tremendous investment the industry is making in R&D." He believes "the public is interested in knowing exactly what the utilities are doing to ensure energy sources in the future and to develop new sources—whether it's solar or wind or some other means." He muses, "I sometimes think there is an innocent out there who is going to find a new way of generating power. But I pity the poor soul because of the regulations he'll have to hurdle to get it into the marketplace."

McCammond notes, "One of the most credible and creditable assets of the public and private utility systems, their investment in research, remains largely unknown. Scientists and technologists (who rank high with the public on the list of those who are believable) are working under our sponsorship on programs and projects—involving $1.8 billion at EPRI alone during 10 years ending 1982—designed to curb the cost of electricity.

"The irate, skeptical consumer—hoping against hope that someone, somewhere, is doing something about the energy mess—gets little comfort from Washington and knows little, if anything, about what his utility has quietly committed itself to do, solely on his behalf. We are ignoring a tremendous asset.

"Our pledge to research should be an integral part of all our information efforts, both locally and industrywide," McCammond says. "The objective is not to soothe our customers or make them love us, but to let them know we not only recognize their problems but also, dammit, we are trying to help do something about them."

Vepco's approach

McCammond explains that Vepco's public information and advertising programs "are designed to tell our customers just what goes into the decisions we're having to make in order to supply them with the energy they want. And we try to supply that information in advance of the decisions, if we can." Vepco's campaign, he is pleased to say, "is effective because the special interest groups are objecting. They don't like it when we go over their heads and speak directly to our customers. If they had their druthers, they'd like to gag us."

Working with the Martin Agency, a Richmond ad agency, McCammond has developed an imaginative, effective advertising and public relations program. The theme of the campaign is "America is a powerful idea. Let's keep it that way." The line appears under the Vepco logo in newspaper ads and is voiced in a series of 30-second television spots. Some examples of the full-page newspaper ads:

□ CLICK appears in bold white against a jet black background and the headline over the copy reads: "If the things people say about making electricity were true, we'd all just turn out the lights and walk home." The copy crisply reviews the facts of coal, oil, natural gas, nuclear, and solar and relates these sources of energy specifically to Vepco. It stresses the critical value of planning and the pressures of inflation. And it points out that as a utility with a public franchise, Vepco has no choice but to meet its customers' growing demand for energy. This means "tough decisions, but someone must make them," the copy says. "They won't be made by turning out the lights and walking away."

□ BOO in large letters appears above two concrete domes that house the reactors at Vepco's Surry Nuclear Station. "The only thing really frightening about nuclear power is the thought of facing the 1980s without it," the copy begins. "Because without nuclear energy, Virginia won't have enough electric power by 1985. It's as simple as that." The copy assures the reader that "your family would be as safe living next to a nuclear plant as you are in your own home." It goes on to say that Vepco's "hard decision to plan and build nuclear plants made over 15 years ago is paying off today." The electric bills of Vepco customers in 1977 "would have been $60–$90 million higher if coal or oil had been used instead," it says, and goes on to explain, "If we are going to have the electricity we'll need in the 1980s, we'll need nuclear power as part of a balanced generating system. And we'll need your help in bringing about meaningful conservation now. That's the only way we're going to make it through the 1980s."

The 30-second television spots focus on energy audits, conservation, and meeting the energy needs of tomorrow. Some examples:

□ A system operator is shown at work in Vepco's power control center, illustrating what he does to make available to the company's customers the most efficient energy to meet electricity demand on a given day.

□ A man is at his desk at home, paying the month's bills. More than one lamp is on beside him. His wife approaches and switches off one of the lamps just as he picks up their Vepco electric bill. He says he doesn't work for Vepco, but, like his wife, he's an energy controller—controlling the energy in their home. The spot is intended to encourage people to be conscious of energy and to use it conservatively.

Utility-customer bond

Returning to his theme of the need for utilities to rebuild bridges to their customers, McCammond says, "We've got to find ways of crossing those bridges to be on the side of the customer again so that special interest groups and politicians cannot drive a wider wedge between us. The utility and its customer are linked in a closer bond of community interest than the customer is with all the politicians, all the self-appointed people who refuse to accept responsibility for energy sources, but merely attack the sources and the utility system.

"I'm convinced," says McCammond, "that a well-informed public that understands the problems faced by energy suppliers is a stronger, more positive force for good than any of these organized groups that claim to represent the public."

He adds, "If Congress and the White House cannot move soon to develop a firm energy policy, then the industry has got to go ahead and do it for them."

At the Institute

Science Attachés Briefed

Twenty-two science and technology counselors and attachés assigned to U.S. embassies and missions overseas were briefed by EPRI during their annual conference in Washington. EPRI Washington Office Director Robert Loftness detailed EPRI's international activities and cooperative agreements, and Energy Analysis and Environment Division Director René Malès reported on results of economic and environmental research.

During informal conversations, a number of counselors stressed the central role of energy issues in their work in foreign countries. Dr. Allen Vander Weyden, counselor at the U.S. embassy in Ottawa, Canada, estimated that the science specialists spend more than half their time on energy matters. "In recent years, a large part of this has been spent on nuclear nonproliferation matters," he said. "The next largest piece of time is spent on environmental issues, such as oceanic and atmospheric pollution problems."

Energy is also a major concern of Counselor Alan Greenberg's work at the U.S. Embassy in Moscow. Coal, oil, and gas fields in the populated western part of the country are being depleted, he explained, and the Soviet Union is beginning to exploit the resources of the remote, but energy-rich eastern section (Siberia). High-voltage transmission is a key area of Soviet interest, he noted, as well as the fusion-fission hybrid concept and magnetohydrodynamics.

In Paris, where gasoline is priced about 48¢ a liter ($2.10/gal), energy is definitely a prime technology concern, said Counselor William Salmon. He estimates that 60% of his time is spent on energy, and of that, 80% is on nuclear energy.

The counselors and attachés serve in the State Department's Bureau of Oceans and International Enviromental and Scientific Affairs, the primary State Department unit for coordinating U.S. science and technology matters on a global basis.

Specialists Join Staff

Two electrical engineers recently joined EPRI's Washington office. Joseph Porter, veteran of 30 years' transmission experience with General Electric Co. in Philadelphia, joined the staff in June as project manager, Electrical Systems Division. Initially, Porter will be managing three projects on current limiting and one on underground transmission cables.

Wayne Beaty, former senior editor with *Electrical World*, joined the EPRI office in July as field engineer, Communications Division, with liaison responsibility to member utilities. His special emphasis will be rural electric cooperative utilities. Prior to his six years with *Electrical World*, Beaty was chief distribution engineer for West Texas Utilities for fourteen years, where he was responsible for the construction, operation, and maintenance of distribution systems.

With the arrival of Beaty and Porter, EPRI's professional staff in Washington numbers nine.

SVG Seminar Planned

EPRI will sponsor a seminar this fall to help utilities evaluate the merits of the static VAR generator (SVG) and to provide them with information on incorporating SVGs into their systems.

EPRI Project Manager Ivars Vancers reports that SVGs may replace mechanically switched shunt capacitors used today at transmission voltages to balance power flow.

The seminar, to be held on October 24 and 25 in Duluth, Minnesota, will feature a discussion of results of an EPRI research project to design, develop, install, and field-test a thyristor-controlled VAR switch to provide voltage control on a 230-kV transmission system. The R&D was done by Westinghouse Corp. and the host utility was Minnesota Power & Light Co.

Utilities and suppliers will report on other installations in operations and on systems recently purchased for implementation in the near future. Suppliers of SVGs will present the latest developments in equipment and hardware.

Those interested in attending this seminar should contact Ivars Vancers at EPRI.

Assessment Guide Available

The 1978 edition of EPRI's popular *Technical Assessment Guide* was published in late July. The guide was originally developed for use by EPRI R&D planners and first published in 1977. It establishes guidelines for evaluating new technologies from the perspective of the electric utility industry and has come to be considered an invaluable tool by industry planners and decision makers, by consultants, and by project contractors.

The guide, which is updated and published each year, contains two kinds of information:

- Data on cost, performance, and other characteristics of generation and transmission options already in existence or being worked on by EPRI
- A standard methodology for comparing alternative technologies (e.g., a conventional coal-fired plant and a gasification–combined-cycle plant), using the utility principle of minimum revenue requirements (i.e., least cost to the customer).

The methodology takes into consideration a comprehensive set of elements: transmission costs and losses; energy costs, capital costs; operating characteristics, typical sizes of plants; and assumptions about plant sites, fuel costs, costs of money, availability of various fuels, commercial availability of new technologies, and so on. Moreover, data in the guide are rated according to a numerical scale that expresses the "confidence level" of the data.

Those who have the previous edition of the guide should note that this year's document contains additional data on new technologies and has been reorganized for easier reference.

The guide has been distributed to information coordinators of all member utilities and to all members of the industry advisory structure. Requests for additional copies of the guide should be directed to Research Reports Center.

DOE Official Visits EPRI

Michael J. Tashjian, director of DOE procurement and contract management met with key EPRI management to become better acquainted with EPRI's research program. From left: Floyd Culler, EPRI president; Tashjian; Chauncey Starr, EPRI vice chairman; and David Saxe, director of the EPRI Administration Division. Discussions between the two organizations are presently under way to update a joint agreement on program coordination and other cooperative efforts.

Radiation Protection Discussed

EPRI Biomedical Studies Program Manager Leonard Sagan, M.D. (left) talked with Director Dr. Andrew McLean (center) and Deputy Director David Richings of Great Britain's National Radiation Protection Board about the recent hearings on the Windscale Nuclear Power Plant expansion in England. In addition to discussing this project, McLean and Richings also spoke with EPRI staff on radiation protection practices and nuclear waste disposal research in the United Kingdom.

Project Highlights

Solar Receiver Arrives

Can the sun's energy be captured at sufficiently high temperatures for the commercial production of electric power? This is the major question EPRI and DOE will pursue during a joint testing program at the government's new Solar-Thermal Test Facility in Albuquerque.

The first of two solar-power tower receivers, developed for EPRI by Boeing Engineering & Construction, arrived August 3 at the facility. Tests using the 15-ft-high (4.6-m), eight-sided unit will help researchers determine if it can heat gas for the efficient production of electric power.

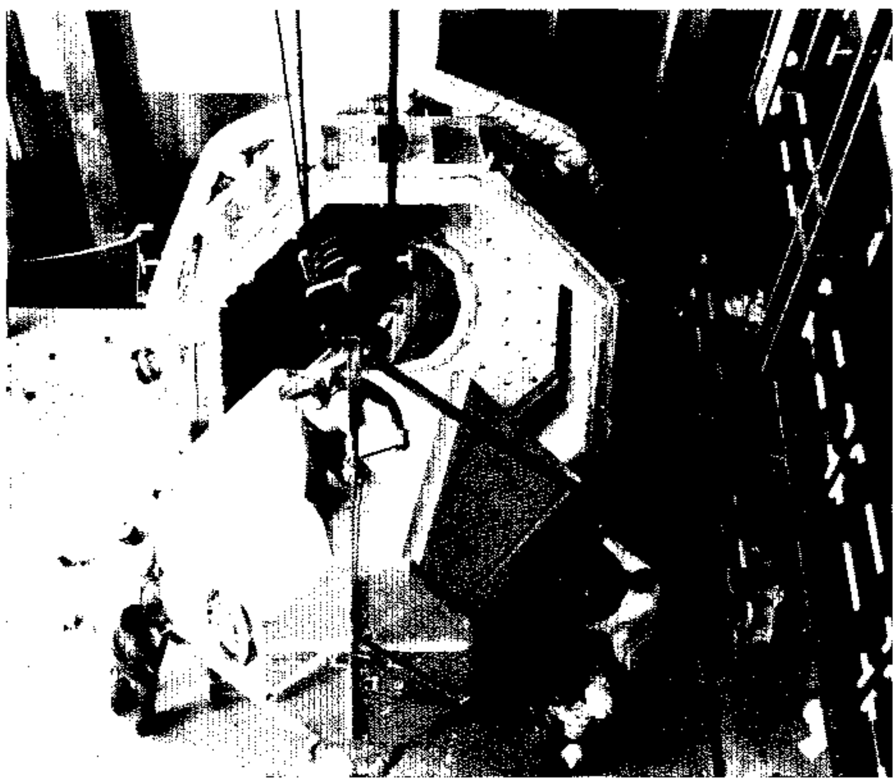
Successful testing of this receiver represents a major milestone in establishing the technical feasibility of high-temperature, gas-cooled solar-thermal power plants. Other studies and projects are under way to determine the system and economic viability of this solar-electric technology, which could lead to operation of an experimental solar power plant by the mid-1980s.

In a power tower system, a large array of tracking mirrors reflects solar energy onto a central receiver or heat exchanger located on top of a large central tower. Gases inside the receiver are heated for use in turbines.

The central receiver concept has been vigorously pursued by EPRI and DOE because it is nearer to commercial reality than any other solar-thermal technology. While the government's first-generation efforts would use the sun's energy to produce steam to turn turbines for electricity (for example at the proposed plant at Barstow, California), projects sponsored by EPRI would use air or helium to turn gas turbines. DOE will deliver and start testing the first of three water-steam receivers later this year.

The EPRI second-generation concept includes dry cooling, which significantly reduces the power plant water requirements. This is an important consideration since many solar plants will probably be situated in arid regions of the United States.

Tests of the EPRI-Boeing solar experimental receiver will enable researchers to investigate whether it can successfully use the sun's rays to heat gas for electricity production. The solar central receiver concept uses a receiver mounted atop a high tower to accept the sun's rays reflected by hundreds of ground level mirrors.



Boeing has been developing the receiver—the electric utility industry's first—since December 1974. It will use eight superalloy-metal heat exchanger panels to heat air to 816°C (1500°F); the superalloy-metal is required for high-temperature operation.

Another EPRI contractor, Black & Veatch, is developing a receiver that will use ceramic-tube heat exchangers. This receiver is designed to heat air to even higher temperatures—up to 1093°C (2000°F). It is slated for delivery to the Albuquerque site in 1979.

The EPRI–DOE receiver test program is expected to continue into the fall of this year. It is hoped it will prove the superalloy-metal design and provide information on how the concept will work in a commercial solar plant. The emphasis of the test program is on proving the receiver design rather than producing electricity.

Questions concerning the economic feasibility and long-term reliability of the central receiver concept will be answered in future studies.

New Method for Detecting Condenser Leaks

EPRI and Science Applications, Inc. (SAI) have developed a new method of using existing leak-detection systems to find hard-to-detect condenser leaks in nuclear power plants, thereby helping to increase plant availability.

In the new leak-detection method, helium and sensitive helium detectors are used to locate leak areas from the face of the condenser tubesheet (the plate at one end of the condenser to which the cooling tubes are attached).

A plenum, or hood, through which helium will be released, is placed against the tubesheet face. The hood reduces the area of the tubesheet being exposed to the release of helium, thus reducing the number of tubes being checked at one time. After the condenser cooling water is drained, a fan placed on the opposite side of the condenser draws the helium into the tubes and sweeps the residual background helium to prevent helium buildup from masking the leak measurements. When the helium is released, the air ejectors are checked on the secondary side for indication of helium. The area of leakage is identified by the detection of helium in the air ejector. In an area of leaks, individual tubes can be checked by releasing helium down each tube.

Leak location along the length of the tube can be fairly accurately estimated by measuring the time delay between release of the helium charge and pickup by the helium detector. The farther from the tubesheet the leak is located, the greater the time delay.

For its first application, the new method was recently used successfully to locate condenser leaks at the Indian Point-3 station of the Power Authority of the State of New York, which has had trouble locating leaks too small for detection by conventional methods.

In one area of the condenser where a leak was indicated, release of helium down the tubes failed to identify a leaking tube. Reducing the plenum area from 25 cm × 50 cm to about 10 cm × 10 cm localized the leak area sufficiently to locate a tiny crack in the tube-to-tube sheet weld.

It is believed that if procedures are tailored to the design of the particular condenser being tested, a plenum examination could be completed in four to six hours. Estimates of the method's sensitivity indicate that leaks smaller than 0.01 g/min can be identified.

EPRI Negotiates 40 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP779-19	Characteristics of Coal Liquefaction Residues	8 months	28.5	Pennsylvania State University *W. Rovesti*
RP1030-3	Development of Stabilizers for Coal/Oil	19 months	64.7	University of Massachusetts at Amherst *W. Slaughter*
RP1086-3	Economic Comparison of Hydrogen Production Methods	2 months	15.0	General Electric Co. *B. Mehta*
RP1088-2	Load Leveling on Industrial Refrigeration Systems	17 months	63.0	Planning Research Corp. *Q. Looney*
RP1180-1	Evaluation of a Gulf Coast Lignite-Fired Atmospheric Fluidized-Bed Combustion Power Plant	5 months	49.5	Burns and Roe, Inc. *C. McGowin*
RP1180-4	Preliminary Feasibility Study of Coal-Water Slurry Systems for Oil-Design Power Plants	7 months	42.4	Combustion Processes, Inc. *S. Ehrlich*
RP1180-5	Increased Utility NO_x Control Requirements Resulting From the Clean Air Act Amendments of 1977	6 months	65.2	Flow Resources Corp. *S. Baruch*
RP1191-2	Master Metering 20 Solar and 20 Nonsolar Homes	2 years	51.5	Public Service Co. of New Mexico *G. Purcell*
RP1195-3	Characterization of Magma 11.2-MW (e) East Mesa Binary Power Plant	2 months	8.0	PFR Engineering Systems, Inc. *G. Underhill*
RP1199-1	Concept Screening of Advanced CAS Power Plants	10 months	68.9	United Technologies Research Center *A. Ferreira*
RP1260-3	Drift Measurements for Mechanical-Draft Cooling Towers	3 months	56.3	Environmental Systems Corp. *J. Maulbetsch*
RP1266-6	Educational Research in Solid-Fuel Technology	8 months	49.0	Technical Education Research Center—Southwest *J. Dimmer*
RP1266-7	Development of Advanced Rotor-Bearing Systems for Feedwater Pumps	8 months	47.3	Dr. Maurice L. Adams *J. Dimmer*
RP1351-1	Energy Conservation Through Reduction of Air Infiltration in Electrically Heated Houses	17 months	145.0	Johns-Manville Sales Corp. *E. Ehlers*
Nuclear Power Division				
RP308-14	Injection Dynamic Sled Tests	6 months	105.0	DOE *G. Sliter*
RP355-11	Model for Fission-Product Release From UO_2 Fuel	5 months	25.0	SRI International *H. Ocken*
RP814-2	Updating and Implementation of the DATATRAN Database Manager	23 months	235.6	Technology Development Corp. *R. Whitesel*
RP965-6	Experimental Data Base for Fluid/Structure Interaction	1 year	47.5	Aeronautical Research Associates of Princeton, Inc. *J. Carey*
RP1162-1	Visualization of Flow Regimes in Steam Generators	16 months	426.5	Acurex Corp. *R. Duffey*
RP1175-2	Chemical and Physical Properties of Hypoiodous Acid	1 year	12.7	University of Texas at Arlington *H. Till*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1176-2	Analytical Support for LWR Fuel Performance Test	1 month	10.0	Science Applications, Inc. *R. Williams*
RP1178-1	Core Performance Benchmarking	8 months	62.8	Southern Company Services, Inc. *W. Eich*
RP1233-2	Phased Mission Analysis Techniques for Improved LWR Availability and Safety	2 years	85.0	University of Tennessee at Knoxville *B. Chu*
RP1251-1	Advanced Methodology for Optimizing PWR In-Core Fuel Management	1 year	89.7	Southern California Edison Co. *W. Eich*
RP1252-2	I–D Kinetics Capability	4 months	24.1	Science Applications, Inc. *B. Zolotar*
RP1329-1	Corrosion Product Dissolution	2 years	115.2	Central Electricity Generating Board *R. Shaw*
Electrical Systems Division				
RP1095-8	Galloping Control by Detuning	10 months	34.3	Aluminum Company of America *M. Silva*
RP1280-1	Laterally Loaded Drilled Pier Research	25 months	444.2	GAI Consultants, Inc. *P. Landers*
RP1283-1	Data Base for Component Outages in Bulk Transmission Systems	2 years	312.8	General Electric Co. *M. Bhavaraju*
RP1359-3	Development of Revenue-Metering Algorithm	14 months	44.7	Ohio University *S. Nilsson*
RP1360-2	Development of Fault Detection Sensors for Gas-Insulated Equipment	1 year	301.2	General Electric Co. *V. Tahiliani*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Energy Analysis and Environment Division				
RP137-3	Residential Thermal Storage	15 months		GPU Service Corp. *R. Crow*
RP330-2	Airborne Field Testing of a Particulate Sulfur Monitor	9 months	32.5	University of Minnesota *C. Hakkarinen*
RP434-19	Rate Design Study: Calculation of Rates and Costs	8 months	127.9	Gordian Associates Inc. *R. Malko*
RP434-22	Rate Design Study: Cost of Load Management to Society	7 months	14.9	Gordian Associates Inc. *R. Malko*
RP934-2	Effects of Electric Fields on Bees—Engineering Support	9 months	19.5	IIT Research Institute *H. Kornberg and E. French*
RP1050-1	Comparative Evaluation of Models of Energy Utilization and Studies of Conservation Technologies	3 years	549.9	University of Arizona Engineering Experiment Station *A. Lawrence*
RP1220-1	Ability to Forecast as Affected by Uncertainty in Supply and Demand Forecasts	2 years	200.0	Resources for the Future, Inc. *A. Halter*
RP1225-1	Controlled Studies of Human Health Effects of Short-Term Inhalation	3 years	1268.7	The Professional Staff Association of the Rancho Los Amigos Hospital, Inc. *J. McCarroll*
RP1308-1	Design for Airborne LIDAR System	2 months	14.9	SRI International *R. Perhac*

Washington Report

Hybrid DOE Office Focuses on Utilities

A year ago, before the establishment of the Department of Energy (DOE), a number of federal agencies administered operations-oriented utility programs. These programs still influence R&D priorities and in many instances correspond to EPRI projects. Rate design, load management, and power plant productivity were managed by the Federal Energy Administration (FEA); power system reliability and interconnections were coordinated by the Federal Power Commission (FPC); and need for power, as well as other utility-related issues, were examined independently by the Energy Research and Development Administration (ERDA).

The diffusion is no more. Within DOE, these and similar activities were coalesced into the Office of Utility Systems (OUS), which was assigned to the Economic Regulatory Administration (ERA) under Administrator David Bardin. ERA administers many of DOE's regulatory programs, including oil pricing, oil allocation and coal conversion. OUS, operating this year with a budget of $15 million and a staff of 120, administers numerous activities involving both electric and gas utilities.

"We're a hybrid group, providing DOE with a focal point for utility programs not specifically involving technology R&D and not related to data acquisition and reporting," explains Jerry Pfeffer, deputy to Assistant Administrator Douglas Bauer and formerly an official with Mitre Corp. and ERDA.

"We're looked to by the whole of DOE as a source of expertise on utility economics, finance, planning, operation, and design—all the various real-world aspects of utility operation. We try to provide an orientation to the needs of utilities so that our perception of real-world problems is translated into R&D priorities on the other side of the shop."

Although the office does exercise direct regulatory authority over utilities in certain matters, Pfeffer likes to think of this regulatory role as "relatively limited" and emphasizes instead the role of working jointly with the industry and state regulatory commissions in seeking common objectives of reliability, economy, and efficiency of service. He characterizes this role as one of "educational, promotional, and advocacy-type activities."

The scope of responsibilities exercised by OUS is wide and diversified. Specifically, the activities are organized into three divisions: Regulatory Assistance, Power Supply and Reliability, and Intervention.

Although the lines of distinction often blur, the divisions can be identified in terms of key public groups and according to their orientation toward supply or demand.

Regulatory assistance

The Division of Regulatory Assistance works primarily with the state public utility regulatory commissions and focuses on issues dealing with customer demand.

"The overall purpose is to assist state commissions in carrying out local initiatives that support national energy policy," says division director Howard Perry, formerly with FEA. "Historically, that has meant rate design, load management, and conservation, but the National Energy Act (NEA) now before Congress broadens that scope to include assistance in a number of other areas." For example, NEA authorizes DOE to provide guidelines, technical assistance, and funding to state commissions for evidentiary hearings in such areas as fuel adjustment clauses, utility advertising, and standards for termination of service.

The Division of Regulatory Assistance works directly with state commissions and indirectly through its support of the National Regulatory Research Institute at Ohio State University in Columbus. Chartered by the National Association of Regulatory Utility Commissioners (NARUC), the institute conducts basic research and provides specific assistance to commissions on regulatory matters. It receives about 90% of its funding from DOE—approximately $1.6 million so far.

As one of its first acts, this division adopted some 25 rate design and load management projects that FEA had managed in conjunction with state commissions and local utilities. These included both demonstration projects, in which experimental concepts were tested during trial periods, and pilot projects, in which commissions were funded to implement changes on a permanent basis. At the present time, officials report, the division is phasing down the demonstration projects (this is the last year) and trying to integrate and analyze the results.

"One of the key points we have learned from all these demonstrations is that no single concept or piece of hardware has applicability at the generic level across all systems and regions," Jerry Pfeffer remarks. "The whole issue of rate innovation and load management has to be dealt with on a system-specific and a region-specific basis. There are just too many different systems characteristics—generating capability, loads, customers—and they will result in widely different responses."

The division is continuing its funding of pilot projects, and some $50 million may be included in the NEA to increase these activities.

"At this time, the major area where there is still considerable work to be done is the assessment of the benefits and costs of the various load management and rate design options prior to implementation," Pfeffer says. "Some of these time-differentiated rates require fairly major investments in metering and load management, and so it is important that the benefits and costs be more clearly understood."

One such cost, he points out, is customer response, and one of the purposes of the rate projects is to help commissions and utilities understand the feelings of the public toward innovations.

"In cases where the benefit-cost ratio may be marginal from an economic point of view, the customer response becomes a significant consideration," Pfeffer maintains. "There may be customers in one region who feel that having the time-of-day option is something they want for conservation reasons or because it provides some control over their costs. The utility in that region may decide to go ahead with a new rate structure to give the customer a greater sense of satisfaction. Conversely, there could be a marginal situation where the complexity of the rate structure could contribute to a deterioration of the credibility of a utility with its customers. That utility may decide not to adopt the new rates." Data from the rate projects should aid utilities and commissions in making these decisions.

Another area of activity assigned to the Division of Regulatory Assistance is funding of utility consumer offices in state governments. These offices represent consumers in electric utility regulatory proceedings. The division reviews funding applications from state governments and provides front-end dollars. It exercises no policy control over the positions advocated by the offices. This year 10 such offices are being funded through Perry's group.

Other responsibilities of the Regulatory Assistance Division include a gas-utility rate design study and the administration of the utility insulation provisions of NEA—the so-called energy audit mandates. This program is administered jointly with DOE's Office of Conservation and Solar Applications.

Power supply and reliability

Shifting focus from the demand side of the picture to supply: the Division of Power Supply and Reliability finds its key public to be the electric utilities.

"Our purpose is to ensure that the nation's electric utility systems continue to satisfy the electricity demands of the public and that they do so in a manner that is reliable, fuel-conservative, and economic," says Jim Workman, deputy to division director Charles Falcone. "The division incorporates the power supply planning, interconnection, and reliability functions that were part of FPC, and the need-for-power analysis and power plant availability activities of both FEA and ERDA."

Director Charles Falcone comes to his position with 10 years of senior utility planning experience. Most of his staff have engineering backgrounds, and Falcone himself has his doctorate in electrical engineering. "Falcone and his major program managers typify our objective of trying to develop a much stronger technical capability within the organization," notes Pfeffer. "The effort extends across the board but is especially important in areas where we exercise direct regulatory responsibility and have the potential to affect systems operation. Our staff has to be able to work at peer level with their colleagues on the technical, engineering, and operational staffs of industry organizations. We've made a special effort in this office to recruit and acquire staff who have a good technical background in the industry, as well as a balanced perspective of the government's dual responsibilities in regulation and cooperative efforts with the industry. There has to be good communication, good interaction, and good credibility."

Pfeffer believes that the Division of Power Supply and Reliability has earned that credibility with both industry and state regulatory commissions. He offers the recent coal strike as an example of the kind of regulatory maturity the organization has attained.

"We had the opportunity during the coal strike to exercise regulatory authority by mandating a number of emergency actions (interconnections, transfers of power) under Section 202(c) of the Federal Power Act," he recalls. "Pressure was building in Congress for some federal action. During that time Falcone moved his base of operations to Canton, Ohio, and continually monitored power flows. We were in close contact with industry and state officials."

Pfeffer maintains that this interaction helped DOE officials realize that "what the industry was doing independently of regulatory prodding was about all that could be done within the existing structure of the electric power network. In other words," he explains, "the amount of energy flowing into the affected areas would not have changed considerably had we issued emergency orders to increase the flow. Conversely, such orders would have had a very high potential for upsetting arrangements that were working effectively. So the fact that we had the authority and chose not to exercise it is a reflection of the maturity of a regulatory organization."

This activity of monitoring the status of electric power systems is the core of the division's program in systems reliability and emergency response. Outages on any system in the bulk power network are reported to program officials, who may, in turn, investigate the outage and make recommendations for possible interconnections or transfers of power in emergencies. This program also has the responsibility for approving international interconnections and exports of power from the United States.

Complementing such systems-related, emergency-response activities, the division has initiated a program in cooperation with the industry and the state commissions to help improve the availability of power plants on a longer-term basis by reducing the frequency and duration of outages. The program focuses primarily on large baseload coal and nuclear generation. One key effort here is cooperative development with EPRI of methodologies for translating the experience of utilities that achieve higher than average availability to those with poorer records. EPRI, DOE, the Edison Electric Institute, and the National Electric Reliability Council (NERC) recently sponsored seminars on this subject and plan a series of workshops this fall to study how to implement the methodology.

The goal of another program in this division is systems coordination. The program staff examines opportunities for power pooling and increased integration when planning for new facilities or the operation of existing plants. Perhaps the most widely publicized effort in this area is a one-year study begun this spring, the National Power Grid Study. Division officials explain that the project was undertaken in response to a request by the late Senator Lee Metcalf of Montana to study the feasibility of a national grid system, such as the one proposed in his bill S. 1991—the National Electrical Energy Reliability and Conservation Act of 1977. The current study is broader, however, than the examination of one concept.

"This study will consider technical, economic, and institutional issues surrounding greater connectivity of the U.S. grid," Assistant Administrator Douglas Bauer noted in announcing the study.

Pfeffer explains further that "DOE is looking at a hierarchy of grid concepts ranging from selected additions to the existing interconnected network to the Metcalf concept of a federally owned and operated generating and high-voltage transmission network that would overlay the existing transmission network. The objective of the study is to look at the benefits and costs of these various options."

Although the study is being supervised by Falcone's group in OUS, other DOE offices, as well as a number of groups representing all segments of the industry, are participating. Input is also being solicited from industry, environmental, and consumer groups through a series of public hearings scheduled for later this year. Deadline for the study report is April 1979.

The power supply plans of utilities are the key focus of a fourth program in this division. Program officials are in close touch with NERC and the regional reliability councils, reviewing utility expansion plans and load forecasts with region-specific questions in mind: Are we going to have shortages of electric power? What is the trend in fuel use? Is this consistent with national energy objectives?

One issue that interests the staff is that of traditional reserve criteria. Pfeffer alludes to the EPRI study that indicated underplanning for capacity may cost consumers more than overplanning.

"What was most interesting to us about that entire work was not the precise numbers but the shape of the curve—the fact that it is so asymmetric—that the costs to consumers of undercapacity so completely dominate the costs of overcapacity for any value of kilowatthours unserved you want to plug in," he noted. "This analysis appears to suggest that U.S. utilities should be operating at much higher reserve levels than even the most conservative utility would suggest right now. This work is currently under review by OUS staff and will be the subject of much discussion in the coming months."

The fifth program in the Division of Power Supply and Reliability is a new and small activity called systems analysis and technical studies. The focus here is on investigating what can be done from a regulatory standpoint to support the introduction of new technologies—solar, wind, cogeneration—into electric power systems. The objective, as Pfeffer explains it, is to provide "technical credence to an area too frequently dominated by rhetoric."

Intervention

The third and final division in OUS is the Intervention Division headed by Grey Staples, formerly general counsel to the Virginia State Corporation Commission. The purpose of this division is to act as DOE's policy advocate, presenting the department's position in proceedings before such regulatory bodies as the Federal Energy Regulatory Commission (FERC), state public utility commissions, and other state and federal regulatory bodies.

This DOE intervention activity has its roots in FEA amicus briefs that were filed when FEA was invited to present its point of view on various rate innovations before regulatory groups. DOE can intervene in state proceedings on its own motion, but has "kept a relatively low profile thus far," Pfeffer explains, "because NEA is still up on the Hill." The pending energy bill specifies the role DOE should play in such interventions.

"In this interim period there is a major effort under way in conjunction with the General Counsel's Office and the Office of Policy and Evaluation to develop the DOE position that will be used as the basis for state interventions under NEA," he says. "However, this effort has not deterred the division from taking an active role in proceedings before federal regulatory agencies on issues ranging from establishing the proper basis for setting unit-train coal rates to facilitating private investment in the nation's first commercial-scale coal gasification facility." Another responsibility of the division is to review and approve rates of the federal power marketing agencies, such as the Bonneville Power Administration.

Reflecting the industry

By pulling together such wide ranging activities into a single organizational unit, the Office of Utility Systems is indeed a hybrid group. In a sense, this reflects the diverse nature of the utility environment. As Jerry Pfeffer explains it, "I see a tremendous heterogeneity in utilities today, both in terms of their management philosophy and their operating practices. I don't think there is a single perspective that dominates the industry any more, if there ever was one. And I think this is probably a very healthy sign."

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

FLUE GAS DESULFURIZATION

The overall objective of the Desulfurization Processes Program is to develop the most cost-effective flue gas desulfurization (FGD) technologies that can satisfy regulatory requirements. So far, this objective has been pursued through the evaluation of established technology and development of emerging technology. Two projects directed toward evaluating established technologies showed (1) that flue gas from utility boilers fired on western coal can be scrubbed using fly ash to provide at least part of the alkalinity (RP785-1) and (2) that two sludge fixation processes are commercially available that can significantly improve the properties of FGD scrubber sludge for disposal in a pond or landfill (RP786-1). Another completed project provided information on, and suggestions for future development of, three commercially available FGD processes (RP536-1).

The abatement of sulfur oxide emissions from utility boilers is presently a technology-forced challenge. That is, the clean air regulations currently being promulgated for new sources are based on the most advanced existing technologies, even though some of them have been demonstrated only at relatively small scale. (Clean Air Act Amendments of 1977 are discussed in the *EPRI Journal*, April 1978, p. 44.) This regulatory approach exerts pressure on EPRI to identify the FGD technologies that are fundamentally sound and to move these technologies toward commercial feasibility as rapidly as possible. Accordingly, the three-phase strategy of the Desulfurization Processes Program is to: evaluate on a continuing basis the established technologies and develop design and operating guidelines; evaluate and develop emerging technologies through pilot plant tests and operation of integrated prototype systems; and participate in the demonstration of commercial-scale scrubbing systems.

The major objectives being pursued through this strategy are to develop a complete and accurate design basis for state-of-the-art scrubbing systems, to eliminate sludge disposal as a major problem, and to develop practical, regenerable FGD technologies capable of producing a marketable form of sulfur.

These objectives were addressed in three recently completed projects, whose results are summarized below.

Established technologies

Although western coals typically have relatively low sulfur content, the boilers burning them may still require SO_2-scrubbing systems in order to comply with federal and state emission standards. Since a large fraction of the alkali content of these coals is in the form of calcium, it is of interest to know if the alkali content of the coal can be used in scrubbing SO_2 from the boiler flue gas. Arthur D. Little, Inc., characterized western coals and lignites and collected pertinent pilot-plant and full-scale scrubber data in order to answer this question (FP-595). It was found that scrubbing systems that use fly ash alkalinity can be successfully applied for SO_2 control on boilers burning low-sulfur western coals. In most cases, a supplementary alkali source must be provided because of the wide variability of the ratio of alkali to sulfur in the coal. However, there is no reliable way to predict the alkali availability of the fly ash by using conventional analytic techniques (e.g., elemental analysis of the ash) and information on the boiler design. This means that requirements for supplementary alkali cannot be estimated precisely. But sufficient data are available to specify several other performance characteristics of the scrubbing system, namely particulate removal, SO_2 removal, oxidation, scaling, and water balance.

Most FGD systems now in operation are based on nonregenerable technologies—those in which the alkali scrubbing reagent is rejected after use. These systems produce significant quantities of sludge, which must be disposed of. A report by Michael Baker Jr, Inc., *State of the Art of FGD Sludge Fixation* (FP-671), discussed an approach for easing this disposal problem (RP786-1). A treatment process called fixation results in solidification and hardening of the sludge to a claylike material. The hardening improves not only the physical properties of the sludge (reduced friability and/or permeability, increased shear strength) but also its chemical stability (rate of release of pollutants to the environment). The study identified two vendors, Dravo Corp. and IU Conversion Systems, Inc., that have sludge fixation systems that are sufficiently developed and tested to be considered commercially available for FGD application.

Based on operating costs for a hypothetical 1000-MW generating station, the incremental (additional) costs for fixation beyond the costs for disposal without fixation were estimated to be $2.50 per ton of dry sludge for disposal in a landfill and $6.90 per ton of dry sludge for disposal by ponding. The significantly higher incremental costs for the ponding method result from the fact that ponding is a simple, inexpensive

UPDATE—FGD PROCESS ENERGY USE CALCULATIONS

In the June-July 1977 *EPRI Journal* (p. 54), Table 5 showed an energy penalty of 1420 Btu/kWh for the copper oxide (Shell–UOP) process, based on results from an EPRI report (FP-272) prepared by Radian Corp. The energy use calculation has been revised on the basis of new Shell–UOP data, and an addendum to FP-272 will be published and available about August 31, 1978. The change results from process modifications that reduce energy consumption by about 40%. Process energy use decreases from 1420 Btu/kWh to 796 Btu/kWh, according to Radian's reevaluation.

technique, and adding fixation requires considerable additional equipment; disposal by landfill, on the other hand, already involves much of the equipment required for fixation. Since these estimates reflect only the additional cost of fixation, they do not indicate whether landfill or ponding will be preferred at a specific site.

Emerging technology

During 1975 and 1976, three 20-MW prototype FGD systems were evaluated by Southern Company Services, Inc., at the Scholz generating station of Gulf Power Co., near Chattahoochee, Florida (RP536-1). These processes were:

- The concentrated sodium absorption–lime regeneration (dual alkali) process of Combustion Equipment Associates, Inc., and Arthur D. Little, Inc. (CEA–ADL)
- The dilute sulfuric acid absorption (Chiyoda Thoroughbred 101) process of Chiyoda Chemical Engineering & Construction Co., Ltd.
- The activated-carbon dry-adsorption process of Foster Wheeler Energy Corp. and Bergbau-Forschung GmbH.

The results of this evaluation program are described in detail in a three-volume report (FP-713). Selected results from the evaluation are shown in Table 1. Of particular significance to the EPRI FGD efforts were the following conclusions.

First, both the dual alkali and dilute sulfuric acid systems were highly resistant to short-term process upsets. Second, the dual alkali and dilute sulfuric acid systems removed little or no NO_x. Limited data showed that NO_x removal by the carbon adsorption process averaged 20%. Third, operability of the carbon adsorption system was poor during this project, mainly because of mechanical problems. (Bergbau-Forschung's carbon adsorption system in the Federal Republic of Germany has operated more satisfactorily.)

As a result of several evaluation studies, including the above work as well as RP535-1 (described in the June-July 1977 issue of the *EPRI Journal*), three emerging technologies have been selected for major program emphasis and potential EPRI participation through the 100-MW demonstration stage. In the coming months, priority will be given to locating appropriate utility sites for these large-scale demonstrations. The technologies are: Chiyoda Thoroughbred 121; Dowa Mining Co., Ltd., basic aluminum sulfate absorption; and absorption—steam stripping—Resox (ASR). The latter is described here as an example of the level of effort that has been undertaken. ASR is attractive because it is conceptually simple, it is a regenerable process producing a marketable product (elemental sulfur), and the projected costs are comparable to nonregenerable scrubbing (e.g., lime/limestone scrubbing).

In the ASR combination, SO_2 is absorbed into a buffered (pH-stabilizing) aqueous solution. This scrubbing solution is regenerated by passing steam through it to desorb the SO_2. The concentrated SO_2 off-gas then goes to a Resox system, where it is converted to elemental sulfur, using coal to reduce the SO_2. Development of this promising combination is being carried out through six interdependent EPRI projects.

- Laboratory testing of alternative absorption–steam stripping chemistries at University of Texas (TPS77-747)
- Laboratory refinement of the Resox process by Foster Wheeler (RP1257-1)
- 42-MW prototype testing of the Resox process in Germany by Foster Wheeler and a group of German partners (RP784-2). Figure 1 shows the prototype Resox regeneration unit
- 1-MW pilot testing of absorption–steam stripping by TVA at its Colbert steam plant (RP1258-1)
- Design of the Colbert pilot facility; design and engineering cost estimates for 100-MW and 500-MW ASR systems by Stearns-Roger, Inc. (RP1258-2)
- A planned 100-MW demonstration of the integrated ASR system, beginning in 1979.

Program Manager: George Preston

Table 1
EVALUATION OF THREE FGD PROTOTYPES

Process	SO_2 Removal Efficiency (%)	Lime Utilization (%)	Electric Energy Use (% generation[a])
Dual alkali (CEA–ADL)	90–96	93–95+	1.3–2.5
Dilute sulfuric acid (Chiyoda 101)	82–98	95–97	3.2–4.5
Carbon adsorption (Foster Wheeler and Bergbau-Forschung)	70–90	Not applicable	1.5–2.5

[a]Energy for reheat is not included because the amount required is highly site-specific

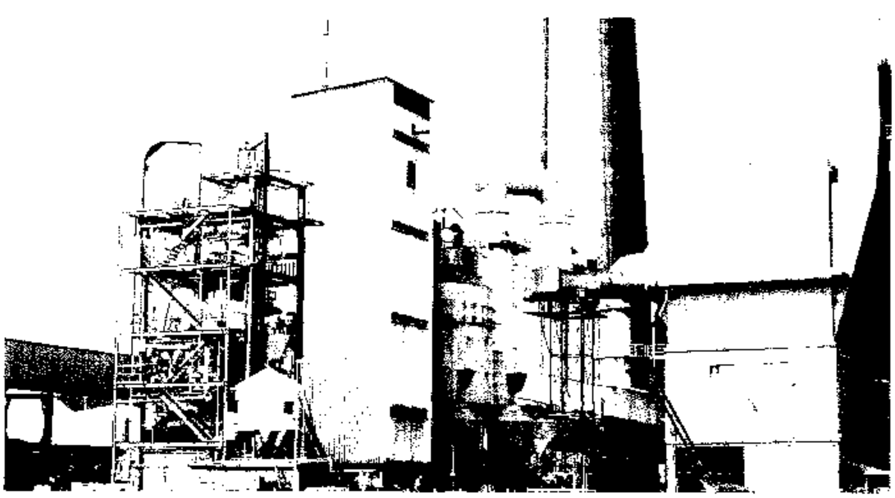


Figure 1 The Resox process for converting SO_2 to elemental sulfur using coal as a reductant is being demonstrated for EPRI at a 42-MW prototype plant in Lünen, Federal Republic of Germany, by a consortium of contractors headed by Foster Wheeler Energy Corp. The Resox system receives SO_2-rich gas from a Bergbau-Forschung carbon adsorption SO_2 removal unit. Construction of the Resox plant was completed in May 1978, and the test program is scheduled to extend through May 1979.

ENERGY UTILIZATION AND CONSERVATION

The Energy Utilization and Conservation Technology (EUCT) Program, which was created to deal with research, development, and demonstration (RD&D) on energy end-use hardware, is oriented primarily toward electricity load management, efficient energy use, reject heat recovery, and efficient substitution of abundant and/or renewable resources for oil and gas, which are becoming scarce.

Imported oil now accounts for about 50% of the oil consumed in the United States, and pressure to shift energy consumption patterns away from oil and gas toward coal, nuclear, and renewable resources is expected to increase. At the same time, financial, regulatory, environmental, and future fuel supply constraints (although differing dramatically in impact among various regions in the highly complex U.S. energy system) have raised serious concerns about the electric utility industry's ability to meet the growing demand for electricity in the 1980s and beyond. Thus, there are two major industry goals that are receiving intensified attention: to prepare for a shift of national fuel dependence from limited to more abundant energy resources and to improve the efficiency of the electric energy system so that relief from dependence on imported oil can be achieved with the least possible drain on scarce U.S. resources. RD&D relating to the end use of energy can make significant contributions to the achievement of these goals.

The proper role of EPRI in this area, however, has to be determined in a complex environment, which involves ongoing programs involving at least four other types of organizations or groups—utility companies, equipment manufacturers and designers, government agencies, and end-user groups. A great deal of communication among these groups and the EUCT Program staff has gone into the development of the current program, and this communication continues to be highly important. The EUCT Program has identified four major RD&D objectives around which most of the program is organized:

- Develop effective and economically sound load management equipment and systems acceptable to users

Table 2
ENERGY UTILIZATION AND CONSERVATION TECHNOLOGY PROGRAM

RD&D Objectives Related to Energy End Use	Projects	Complementary Projects
Improve efficiency of electric energy system		
Develop effective and economically sound load management equipment and systems acceptable to users	RP844: Load management using an integrated solar collector, heat pump, and thermal storage system (project cofunded with EPRI Solar Program) RP1088: Load leveling on industrial refrigeration systems RP1089: Cool storage instrumentation and data verification RP1090: Heat storage instrumentation and data verification	EPRI: Demand and Conservation Program, Electric Utility Rate Design Study, Energy Storage Program, Distribution Program, Solar Program Non-EPRI: Edison Electric Institute (EEI), American Public Power Association (APPA), National Rural Electric Cooperative Association (NRECA), Department of Energy (DOE)
Develop and implement efficient energy end-use systems compatible with utility operations	RP789: Development of advanced air source heat pumps (project cofunded with Niagara Mohawk Power Corp. and Carrier Corp.) RP1275: Advanced heat recovery–thermal storage systems for industrial applications RP1351: Field test of air infiltration barrier for buildings Planned: Hybrid fuel heat pumps, electrolytic processes, agricultural processes, and lighting systems	EPRI: Solar Program, Distribution Program Non-EPRI: EEI, APPA, NRECA, DOE
Develop techniques and systems for reject heat recovery and utilization (DEUS and others)	RP1087: Heat recovery from refrigeration systems RP1274: Utilization of heat rejected from major transformer substations RP1275: Advanced heat recovery–thermal storage systems for industrial applications RP1276: Evaluation of alternative technologies for DEUS	EPRI: Fuel Cells and Chemical Energy Conversion Program, Water Quality Control and Heat Rejection Program, Demand and Conservation Program, Supply Program, Distribution Program Non-EPRI: DOE
Prepare for fuel dependency shift		
Develop techniques and systems for efficient substitution of electricity and renewable resources for scarce fuels in major energy end-use applications	RP789: Development of advanced air source heat pumps (project cofunded with Niagara Mohawk Power Corp. and Carrier Corp.) RP844: Load management using an integrated solar collector, heat pump, and thermal storage system (project cofunded with EPRI Solar Program) RP1087: Heat recovery from refrigeration systems RP1136: Electric vehicle demonstration RP1274: Utilization of heat rejected from major transformer substations RP1275: Advanced heat recovery–thermal storage systems for industrial applications	EPRI: Solar Program Non-EPRI: DOE

- Stimulate development of efficient energy end-use systems compatible with utility operations
- Develop techniques and systems for reject heat recovery and utilization, such as dual energy use systems (DEUS) and others
- Develop techniques and systems for efficient substitution of electricity and renewable resources for oil and gas in major energy end-use applications.

Table 2 illustrates the relationships between the major industry goals, RD&D objectives relating to energy end use, projects making up the EUCT Program, and complementary projects. Background for most of the projects has been given previously (*EPRI Journal,* December 1977, pp. 39–41).

Effective load management systems

Energy use patterns in a demonstration plant in the southeastern United States have been defined for industrial refrigeration, and a preliminary minute-by-minute simulation of electricity consumption has been completed (RP1088). The next steps will be to refine the simulation and then use it to develop a load management control strategy for the refrigeration system; the plant personnel will implement the strategy in order to validate the simulation.

Eighteen residential cool storage units have been installed and instrumented in a number of states, and another 4 installed units were reviewed for possible instrumentation (RP1089) in time to collect data over the summer of 1978 (Figure 2). DOE's Division of Electrical Energy Systems is sponsoring a complementary project to install and monitor as many as 50 storage units on each of several utility systems. The DOE and EPRI projects are being closely coordinated so that both the performance of the storage equipment and the impact of storage on the utilities' systems can be characterized.

Two heat storage units have been instrumented, and 18 additional sites have been identified for data collection during the winter of 1978–1979 (RP1090). Four system types (pressurized water, slab, central ceramic, and room ceramic) will be included. This project and a companion DOE project have objectives similar to those of the cool storage projects described above.

Economic and performance characteristics will be evaluated for an integrated solar collector, heat pump, and thermal storage system to be installed on the University of New Mexico campus (RP844). Public Service Co. of New Mexico is a sponsor of this project, which is cofunded with EPRI's Solar Program.

Figure 2 EPRI is sponsoring, in cooperation with individual utilities, the field-testing of cool storage units through sophisticated instrumentation. Data from about 20 widely dispersed units are being collected during summer 1978.

Efficient energy end-use systems

Projects are now under way on advanced heat recovery–thermal storage systems for industrial applications (RP1275) and on the field testing of an air infiltration barrier for buildings (RP1351). The contractor for RP1351 is Johns-Manville Sales Corp. and the subcontractor is Public Service Co. of Colorado.

In another project, some design features (including dual speed with a more sophisticated control system) of four prototype heat pumps being field-tested in four northern-climate cities (Seattle, Minneapolis, Boston, and Syracuse) have been incorporated into commercial heat pumps to be marketed for the 1978–1979 winter season (RP789). This project is being cofunded with Niagara Mohawk Power Corp. and Carrier Corp.

Reject heat recovery and utilization

The national distribution of residential central air conditioners and heat pumps has been estimated (RP1087). Work is continuing to determine the size and location of commercial and industrial air conditioning and refrigeration systems and to estimate the technical potential for heat recovery from these systems. Although the major application for the recovered heat in the residential and commercial sectors appears to be water heating, other applications, such as combustion air preheating, are being investigated for industrial use. Commercial and industrial case histories are being developed to provide descriptions of the technical and economic characteristics of the technology.

The City of Seattle Department of Lighting has begun work on a heat exchanger designed to recover useful heat rejected from substation transformers without impairing their reliability (RP1274).

A methodology is being developed through which utilities can assess their opportunities to integrate DEUS into their own systems (RP1276). Before this project was developed, an EPRI-sponsored workshop was held in Yarmouth, Maine, to review available information on DEUS applications, particularly district heating, industrial cogeneration, "total energy" facilities for buildings, and agriculture and aquaculture applications. The workshop produced the following principal conclusions. Since technical and economic aspects of dual energy use are site-specific, it makes little sense to generalize about potential benefits and other points. Direct experience with a number of DEUS installations will be required if economic and fuel use characteristics of the many proposed projects are to be estimated accurately; therefore more demonstrations are needed. It is important to look at the technical and economic issues and not to assume a priori that the institutional barriers to DEUS will be overwhelming. If DEUS projects are to be successful, utilities should play an active role and the nonutility organizations involved in DEUS plans must be exempt from utility-oriented regulations. Development of a capability for using coal or coal-derived fuels in an economically viable way is needed for many DEUS applications; otherwise DEUS will in fact promote further use of scarce fuels.

The proceedings of this workshop (EM-718-W) and a special report summarizing the workshop (EM-718-SR) have recently been issued.

Substitution of electricity and renewable resources for oil and gas

Exploration of the potential for energy conservation and load management represented by electric vehicle (EV) technology is steadily progressing toward hardware implementation. Testing of EV performance characteristics has been initiated at Southern California Edison Co. (RP1136), and the performance data will become a major factor in the ultimate selection of electric vehicles for the field demonstration being designed by EPRI and the host utility, Tennessee Valley Authority. This demonstration will emphasize data collection to be used for characterization of EV performance and energy use and for investigation of the potential impacts of large-scale EV usage on electric utility operations.

The other projects in this category, listed in Table 2, have been described above.

Survey of EUCT projects

A preliminary survey of utility-sponsored energy conservation, load management, and thermal storage projects has been completed, and a draft report is available in limited quantity. The draft report describes 43 energy conservation projects, 43 communication and load control projects, and 55 thermal storage projects being sponsored by electric utility companies. A special report describing the results of this preliminary survey is in preparation, and the survey is being expanded and updated. *Program Manager: Quentin Looney*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

FIBER OPTICS IN UTILITY GENERATING STATIONS

One of EPRI's goals is to bridge the gap between technological advances and practical application in utility generating plants. The advances in fiber optics are being applied in the computer industry, defense instrumentation, and communications. The use of fiber optics as a means of communicating information is increasing rapidly. "Light pipes" are being used for connection of computer terminals, for indication of burned-out bulbs in automobiles, and for message pathways in local telephone systems. An EPRI project will demonstrate the application of fiber optics in the communication network of a utility plant, showing advantages, limitations, and cost information (RP1173).

EPRI plans the in-plant demonstration of fiber optic communication links in the Bergen generating station of Public Service Electric and Gas Co. (PSE&G). E-Systems, Inc., of Greenville, Texas, will provide the technical design and assembled components, and utility personnel will install and maintain the system.

The cost of a length of fiber optic cable has decreased to the point where it is now only a little more expensive than an equivalent length of coaxial cable. A fiber optic system requires a signal conditioner, which changes an electric signal to a light signal by means of either a light-emitting diode or a laser source. It also requires a light-sensitive receiver (a light-sensitive avalanche diode, for example) to sense the signal and another signal-conditioning circuit to change the light signal to an electronic signal that is compatible with follow-on equipment.

Because installation of a fiber optic system is more expensive than that of a hard-wired copper circuit, there have to be performance characteristics that compensate for the higher cost if the system is to be selected. Fiber optic circuits do have several important advantages.

First, because the fiber optic cable is made of either plastic or glass, it is a good insulator. With copper electrical circuits, electromagnetic interference can play tricks with the information being transmitted. Interference from switching or control boards, transformers, generators or motors, high-voltage or high-current circuits, and connecting equipment with different ground potentials can cause problems for plant engineers and technicians who are trying to understand why copper electrical circuit performance is inadequate or below expectations. Fiber optic material is insensitive to these effects (and the sending and receiving circuits can be shielded).

Second, the fiber optic signal is a light beam. Consequently, the variations produced in electrical circuits (cross talk, electromagnetic interference, arcing or shorting due to broken insulation) do not exist in the fiber optic system because the light beam is insensitive to these outside interferences.

Third, fiber optic technology has improved significantly. The Bell System now sends signals without intermediate signal amplifiers up to 10–15 km (6–9 mi), and for shorter distances in experimental installations, it provides signal paths that will carry hundreds of megabits of information per second. Components are becoming available as off-the-shelf items that are compatible with most installations.

Fourth, fiber optic materials can be selected to be relatively insensitive to common environmental variables and to reasonable levels of radiation. (NASA studied the application of fiber optics for use in space probes under long-term radiation.) Although signal transmission is affected by large variations in temperature, circuits can be selected for most normal temperature ranges. The circuits are essentially insensitive to moisture, pressure, and typical room environments.

EPRI is examining high-voltage transmission installations (both ac and dc) that use fiber optics in the substation control circuits because of the hostile electrical atmosphere, characterized by arcing, switching transients, high-gradient fields, and extreme weather conditions (RP560 and RP668). The sending and receiving equipment remains vulnerable to electromagnetic interference and becomes the limiting factor. These are the only installations identified so far that use fiber optics in operating generating units.

Several utilities have suggested that EPRI demonstrate the state of the art of fiber optics so that utilities can decide on its feasibility on the basis of a system installed and maintained by utility personnel. PSE&G of Newark, New Jersey, which is considering the use of fiber optics in its future nuclear plants, believes that a demonstration would ease its regulatory obligations and show the capabilities of the systems now available.

The PSE&G Bergen station (fossil-fired) has recently upgraded its plant information system. The design staff took advantage of multiplexing circuitry, enabling signal sources to be gathered at a central location, sequentially sampled at about 500,000 bits per second, and sent over a single coaxial cable to a multiplex receiver, which separates the signals for use in the computer. This installation is an ideal proving ground for demonstrating the type of fiber optic system that could be used in PSE&G's proposed nuclear plants. The signals are already gathered in the Bergen plant so that the coaxial cable leads have only to be removed and the signals prepared for the fiber optic link, which is inserted in place of the copper-wired circuits. Unexpected installation or break-in problems can be handled by simply reconnecting the coaxial cable while the problem in the fiber optic system is being corrected.

EPRI will use both plastic and glass fiber optic cables in two installations in the Bergen plant. The final report on this project will cover any difficulties with splicing, alignment, installation, operation, and accuracy of transmission and will indicate levels of cost. Manufacturers are being involved to ensure typicality of equipment used. The project will last approximately 12 months, with initial installation of the plastic circuits in the plant scheduled for this year. In-

stallation of the glass circuits will follow the performance review of the plastic circuits.
Project Manager: Roy Swanson

TURBINE MISSILE CASING-EXIT TESTS

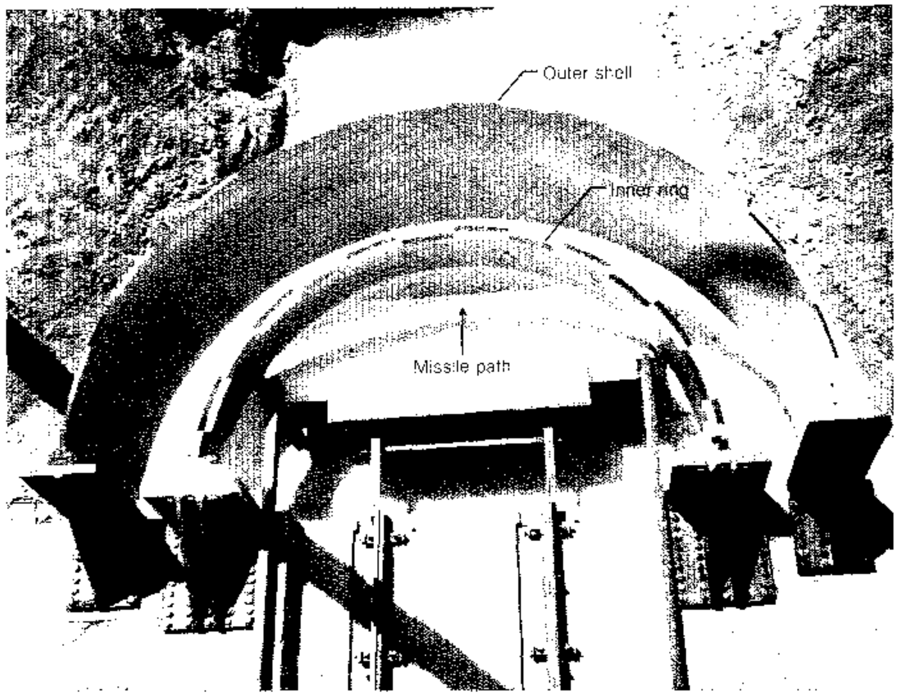
Full-scale rocket sled tests at Sandia Laboratories are providing benchmark data for making more realistic assessments of turbine missile effects. Two tests simulated the energy dissipated by the turbine internal blade ring and outer casing during the exit of a 1540-kg (3400-lb) fragment from a failed shrunk-on disk in the low-pressure stage of an 1800-rpm steam turbine. Depending on the orientation of the missile at impact, the steel test structure either slowed the missile to 60% of its 146-m/s (480-ft/s) initial velocity or brought it almost to rest (an energy reduction of 65–100%). Subsequent tests will examine how well reinforced-concrete walls surrounding safety-related equipment protect it from a turbine missile that exits a casing.

Nuclear plant structures, systems, and components that are important to safety are designed to be protected against the effects of postulated high-energy turbine missiles (*1*). These missiles could be produced by the unlikely failure of shrunk-on disks that support the rotating blades of large steam turbines.

In plants with a "peninsula" arrangement, protection from turbine missiles is provided by installing the turbine so that its axis lies radially from the reactor building; thus, the potential missile trajectories, at right angles to the turbine axis, are not in line with the plant. In plants with a "nonpeninsula" arrangement (with the turbine axis perpendicular to a radius), designers depend on the low probability of missile generation, the still lower probability of a missile striking a safety-related component, and reinforced-concrete walls for an adequate level of protection.

In the current phase of the missile impact program, EPRI is examining the interaction of disk fragments with the turbine internal blade ring and outer casing. Of special interest are the energy dissipation and the trajectory of a disk segment that may be ejected from the casing. The next phase of the program will quantify the resistance of reinforced-concrete structures to turbine missile impact. The key element of both phases is full-scale impact testing at Sandia's rocket sled facility in Albuquerque, New Mexico (RP399). The missile launching technique is similar to that used for tornado missile tests at Sandia's Tonopah, Nevada,

Figure 1 Overhead view of simulated turbine casing structure (13-cm [5-in] thick inner ring, 3-cm [1.25-in] thick outer shell) bolted to massive backup structure.



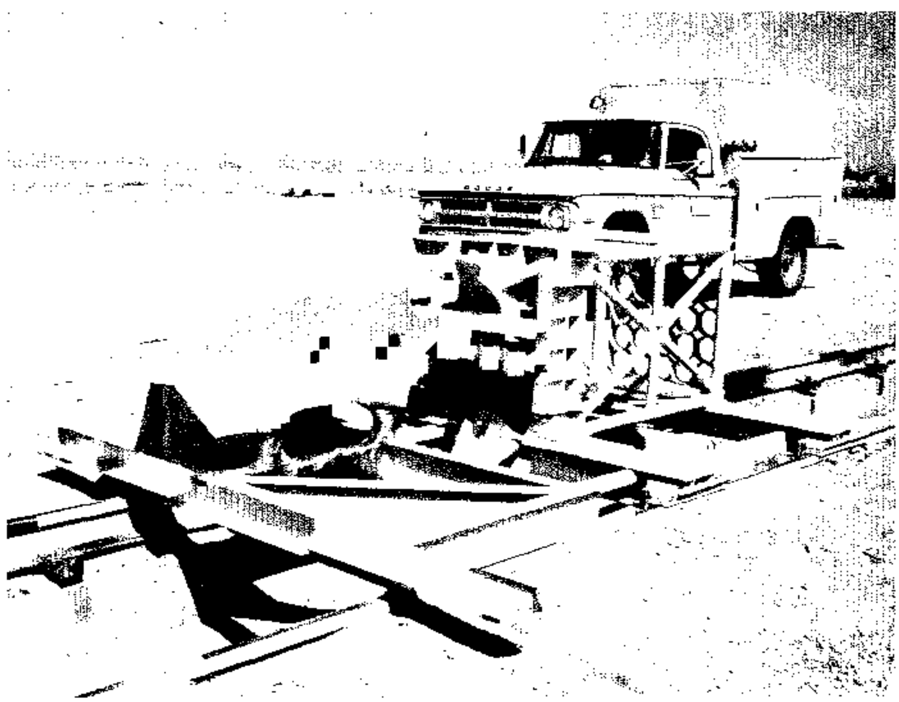
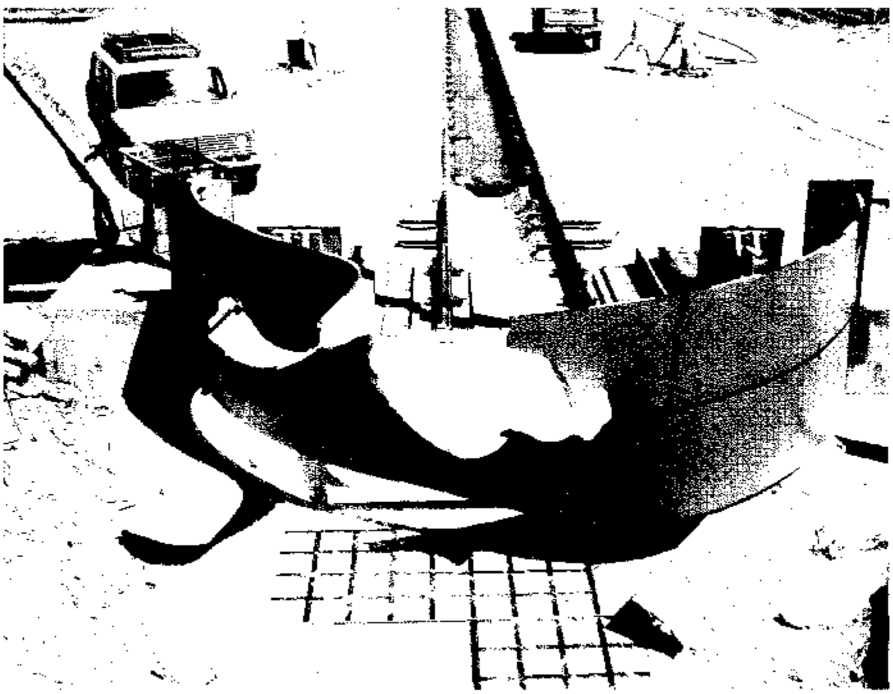


Figure 2 Rocket sled and 1540-kg (3400-lb) turbine missile used in first test at 146 m/s (480 ft/s).

Figure 3 Fractured inner ring and perforated outer shell, which together dissipated two-thirds of missile energy.



site (2). Results from the full-scale casing and concrete tests will be valuable as a data base in making realistic assessments of overall turbine missile effects.

Two full-scale casing-exit tests have been completed. The tests simulated the impact of a failed disk fragment on the turbine internal blade ring and the outer wall of a turbine casing. The objective was to provide benchmark data on both the energy-absorbing mechanisms of the impact process and (if breakthrough occurred) the exit conditions of the fragment. These data may be used for evaluating the estimates of turbine missile exit velocity that are currently being used in plant design and for validating improved analyses that may be developed in the future.

For both tests, the target structure was a simplified representation of the casing of the low-pressure section of a large 1800-rpm turbine (Figure 1). Only the two main semicircular casing components that are expected to absorb most of the energy in a failure were modeled: the internal blade ring or diaphragm, which supports the stationary turbine blades (represented by a steel ring that is 12.7 cm [5 in] thick, 0.5 m [1.66 ft] wide, and 4.3 m [14.1 ft] in diameter); and the outer casing cover (represented by a steel shell that is 3.2 cm [1.25 in] thick, 1.8 m [6 ft] wide, and 6.4 m [20.8 ft] in diameter).

The target ring and shell were bolted to a massive 1800-t backup structure, which consisted of reinforced concrete and soil overburden. The bolted connections closely simulated the horizontal joint in an actual turbine.

Although many of the fragments produced in a turbine failure would be light enough to be contained by the casing, the test missile represented the heavier class of turbine segments considered in design. The missile in both tests was a 120° segment of a last-stage, shrunk-on disk, provided by Westinghouse Electric Corp. (Figure 2). The 1540-kg (3400-lb) segment had no blades—it was assumed that the blades would be broken off or crushed during exit.

In an actual turbine, fragments of a failed disk would leave the shaft with both tangential and rotational velocity. In the tests, the missiles were propelled by a rocket sled to impact the structure at 146 m/s (480 ft/s). This represents a translational velocity giving the same total kinetic energy as a segment leaving a shaft that is spinning at 120% of operational speed (the so-called design overspeed condition).

Since the orientation of the missile at impact with the inner ring has a large influence on the amount of energy absorbed and since the actual impact orientation in a turbine cannot be specified with certainty, the missiles in the two tests were given "bounding" orientations. In the first test, a piercing orientation (with sharp-corner impact and minimum projected area) gave a lower bound on energy absorbed, and in the second test, a blunt orientation (at right angles to the first, with curved-edge impact and maximum projected area) gave an upper bound on energy absorbed.

The target inner ring was heated to the temperature of the end stationary blade ring in a typical operating turbine (38°C; 100°F). Strain gages recorded the structural response of the ring and shell. High-speed cameras recorded the trajectory of the missile prior to impact, during breakthrough, and after exit. High-speed photography was also used to record deflection of the structures as a function of time.

In the test with the piercing orientation, the missile perforated both structures (Figure 3) and was stopped by the soil embankment. In slowing the missile to 60% of its initial speed, the structure absorbed two-thirds of the missile's energy. Another significant fact was that the segment was rotating as it exited the target structure. Designers will be able to take advantage of such off-normal and spinning conditions when calculating the effects of actual missile impact on concrete walls.

In the test with blunt orientation, the missile did not perforate either the ring or the shell. Instead, the momentum that was transferred to the structures pulled the bolts out of the end supports, and the total dissipation of energy brought the missile almost to rest. In an actual turbine, drag on the missile from portions of the casing not in direct line with the missile exit path could be expected to lead to virtual containment of the segment.

Data from the tests are being reduced and compared with the results of pretest calculations and will be included in a final report. The data will provide a benchmark for various calculation techniques used in design. Plans are being considered for additional testing and analysis of missile exits from turbine casings.

Results of the tests described above will also provide a basis for selecting missile velocities to be used for concrete structure impact tests, which will begin late this year and be completed in 1979. *Project Manager: George Sliter; Program Manager: Conway Chan.*

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R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

System dynamic behavior

One of the most challenging problems in the analysis of power systems is that associated with system dynamic behavior, which must be described by differential equations. The solution of the system behavior problem requires careful attention to the mathematical modeling of the system components and controls. Because computer time is very costly, it is usually necessary to choose the simplest model that will preserve reasonable accuracy in important variables. This simplification is sometimes difficult and even controversial.

In developing dynamic simulation tools, the emphasis is on the 1-s–20-min time range. This simulation includes study of transient stability and of mid-term (up to 5 minutes) and long-term (up to 20 minutes) behavior. It also includes research on general concepts for numeric time-related solution of transient behavior and for direct eigenvalue calculation. (The eigenvalue is a mathematical measure of the system's ability to regain equilibrium after a disturbance.) The modeling emphasis is on improving the dynamic models of loads and synchronous machines for use in system dynamic studies in this time range. The entire simulation and modeling effort is directed at the low-frequency performance of the system, and system responses above a few hertz are ignored. The major dynamics are determined by the electromechanical behavior of turbine generators and by system voltage controllers.

The purpose of one project with Boeing Computer Services, Inc., is to study the methods used in the computer programs that perform system stability analysis (RP 670). The goal is to uncover the best of these methods and ultimately to develop a new generation of computer codes that are superior in many ways to today's codes.

In the Boeing study, a large number of solution methods were considered for use in power system dynamic analysis. Preliminary analyses were performed to identify those algorithms that merited further testing and to evaluate their order, accuracy, stability, and complexity. Algorithms were identified that could greatly improve the reliability and efficiency of power system dynamic simulation codes. However, to achieve the full benefit of these improvements, careful attention would have to be paid to algorithm control.

Another project, with Systems Control, Inc., concentrated on the development of a computer program that can derive a simplified representation of a neighboring utility system for transient stability studies (RP763). Typically, the simplified system

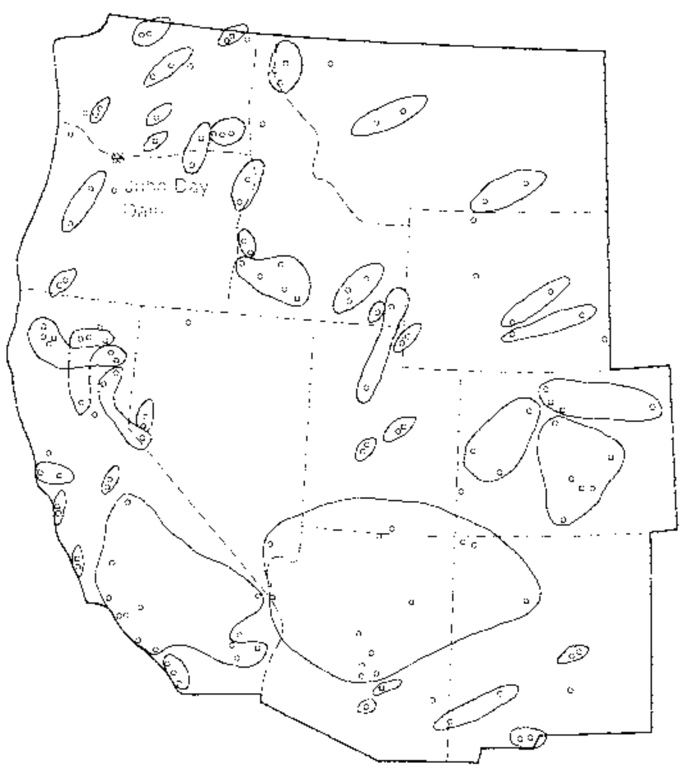


Figure 1 The geographic region of the western interconnected system. A three-phase bus fault is assumed to occur at John Day Dam on the Bonneville Power Administration system. In response to this fault, various generators in neighboring states change speed, some of them coherently (in step). These coherent groups are circled to show their geographic locations.

representation—called the dynamic equivalent—is one-half to one-sixth the size of the full system representation, thereby offering 50% to 80% savings in the cost of computer studies while maintaining adequate study accuracy.

The objective of this project was to further develop, refine, and evaluate the coherency-based (uniform) dynamic-equivalent technique to a point where it is suited for applications in system planning. To achieve this objective, the following work was accomplished.

- A highly efficient method was developed for computing dynamic equivalents without the need for a transient stability simulation of the full system.

- The coherency-based dynamic-equivalent technique was extended to encompass comprehensive models of generating units and loads.

- A comprehensive program was written for forming coherency-based dynamic equivalents. The dynamic-equivalent program has the capacity for handling 2000 buses, 3000 lines, and 350 generators. The program incorporates 2 synchronous machine models, 6 excitation system models, 10 prime mover and governor models, 3 power system stabilizer models, and a nonlinear load representation.

- The methods and programs developed were tested and successfully validated on two large-scale data bases: one (1027 buses, 2163 lines, and 295 generators) representing the eastern U.S. interconnected systems and one (1308 buses, 1934 lines, and 337 generators) representing the western U.S. interconnected systems.

The dynamic-equivalent model is two to six times more efficient than the full-system model in terms of computer running time and memory requirement. Also, the results obtained by using the dynamic-equivalent model are as good as those obtained by using the full-system model.

The success of the dynamic-equivalent technique is illustrated in Figures 1 and 2. A test study was performed on the 1308-bus representation of the western U.S. system. The test area is shown in Figure 1, with the coherent generator groups circled. Some coherent groups include a large number of generators and are spread over large areas. The swing curves for a large group situated mainly in Arizona are given in Figure 2, which shows the nearly uniform (coherent) rotor motion.

A follow-up project, which is nearly complete, has the objective of applying the dynamic-equivalent method to the large eastern U.S. interconnected system. This system, as studied by reliability councils, often consists of more than 6000 buses and presents a challenging problem in the development and testing of dynamic-equivalent models.

The EPRI study was performed in cooperation with the East Central Area Reliability (ECAR) Coordination Agreement. The ECAR system is composed of 5838 buses, 10,008 lines, and 1159 generators. Alternative methods of system reduction, coherency evaluation, and model aggregation were studied. Multipass methods were tried, but it finally became clear that a single-pass method, using a large central processor, was superior. This study produced a dynamic-equivalent system of 277 buses, 1524 lines, and 152 generators. Testing indicated that the dynamic equivalent is acceptable for accurate tracking of important system variables and is a reasonable, cost-effective reduction on a modern, large-scale computer.

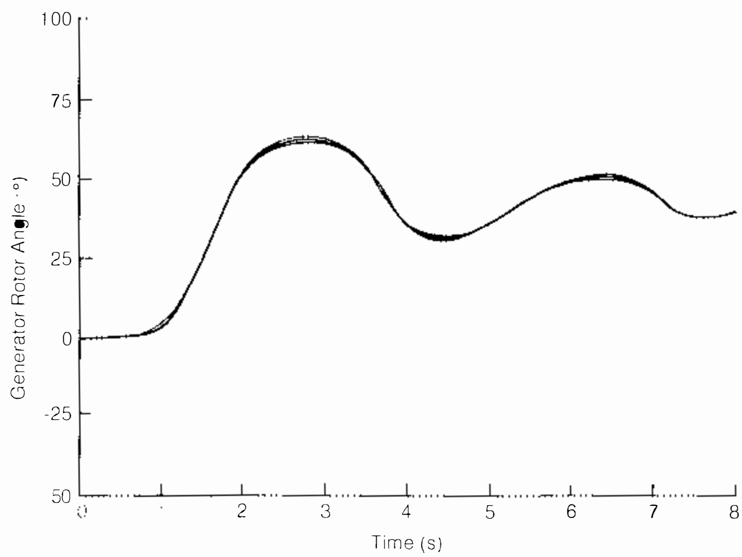


Figure 2 One of the coherent generator groups shown in Figure 1 is in the Arizona area. The coincidence of the stability swing curves for the 21 generators in this group illustrates the high degree of coherency.

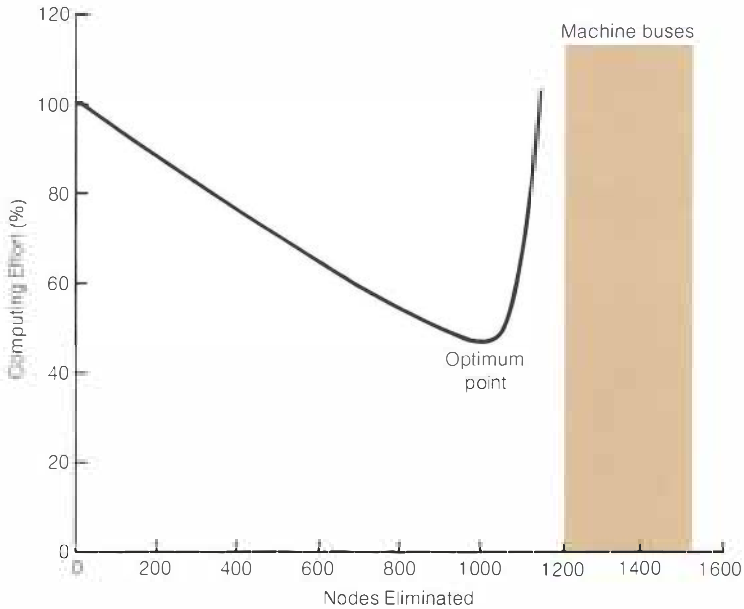
Short-term and midterm simulation methods

Arizona State University and Arizona Public Service Co. (APS) are conducting a project on the development of short-term and midterm simulation techniques for large interconnected electric power systems (RP745). The goal of the project is the development of a computer model that will accurately simulate power system behavior during the short-term (transient) period and through a midterm period, usually defined as the three to five minutes following a disturbance. Most of the effort is concentrated on the development of new computation schemes that will lower the computing cost during this extended period and thereby make the midterm simulation one of reasonable cost and accuracy.

The major efforts in the project are the development of a network reduction algorithm, formulation of a network reduction strategy, coding into a prototype program, and documentation. A step-by-step network reduction technique is used that is sufficiently accurate to provide realistic simulation of a power system with a nonlinear load.

The reduction procedure is accomplished by eliminating a particular nonlinear load. This process is repeated according to an elimination strategy until the computation reaches an optimum (Figure 3). Reduction

Figure 3 With the network solution of the unreduced system considered to be a 100% computing effort, this graph shows the reduction in effort (cost) made possible by reducing the network. Note that the cost increases rapidly once the optimum reduction is reached and can even exceed the original 100%. The machine buses shown to the right are those that cannot be reduced.



beyond the optimum point results in more terms in the remaining equations and subsequent increase in computation time and cost.

Errors introduced by this process were minor on the systems tested. Savings in overall computation time and cost were promising. Tests on a 450-bus test system for a four-minute simulation show that the reduced network case was solved in 70% of the time taken for the same system with full network representation. Further testing and evaluation of the method are planned.

A method for eliminating most of the nongenerator buses from a large power system simulation while controlling the reduction error has been devised and tested. This method requires a periodic base solution and occasional recalculation of the reduction. However, the decrease in computation time is worthwhile, and the realism of the representation is good during the extended simulation period.

A joint project (RP1208) with APS, Arizona State University, Boeing Computer Services, and Systems Control focuses on the use of advanced techniques in extended dynamic stability analysis. This project merges the results of the three projects described above into a single, comprehensive computer analysis tool.

The objective of the project is to develop a transient-midterm stability program that will simulate up to four minutes of real time at a reasonable cost. The transient-midterm stability program will have a variable data structure. This will allow the user to select, compile, and maintain load modules of various sizes with a single transient-midterm stability source code.

The program will include most of the power system models necessary for extended simulation, including those for the network, machines, boilers, automatic generation control, and loads. The program will establish the feasibility of solving problems in the desired size range over the midterm (four-minute) time interval.

The project, a cooperative effort coordinated among the four contractors, was initiated in February 1978 and is planned for completion in late 1979. *Program Manager: Paul Anderson*

UNDERGROUND TRANSMISSION

Water-jet concrete-cutting vehicle

Flow Industries, Inc., has developed a water-jet concrete-cutting vehicle (RP7860). Attached to the front of the vehicle is an articulated boom containing a shrouded water-jet cutting unit. This cutting unit can be moved in all horizontal directions and vertically to direct the water jet where it is needed. The unit can cut 2.1 m (7 ft) across and 1.5 m (5 ft) forwards before advancing to the next area of concrete to continue the cut. Overall advancement rates of 0.01 m/s (2 ft/min) are anticipated.

A prototype of the water-jet concrete cutter (Figure 4) is ready for a follow-up demonstration. Four host utilities will use the vehicle for six months each. The vehicle will be used on new cable routes for the removal of overlying concrete and substrates. Each host utility will give a performance report and cost analysis for the vehicle. It is anticipated that a number of different substrates and trench sizes will be encountered, providing useful data on the endurance and economics of this unique trenching tool. Development of a new attachment will be considered pending demonstration results. The attachment is a handcart-size cutting unit capable of cutting at the same speeds as the boom-mounted unit but designed for work in narrower areas, such as sidewalks. *Project Manager: Thomas Rodenbaugh*

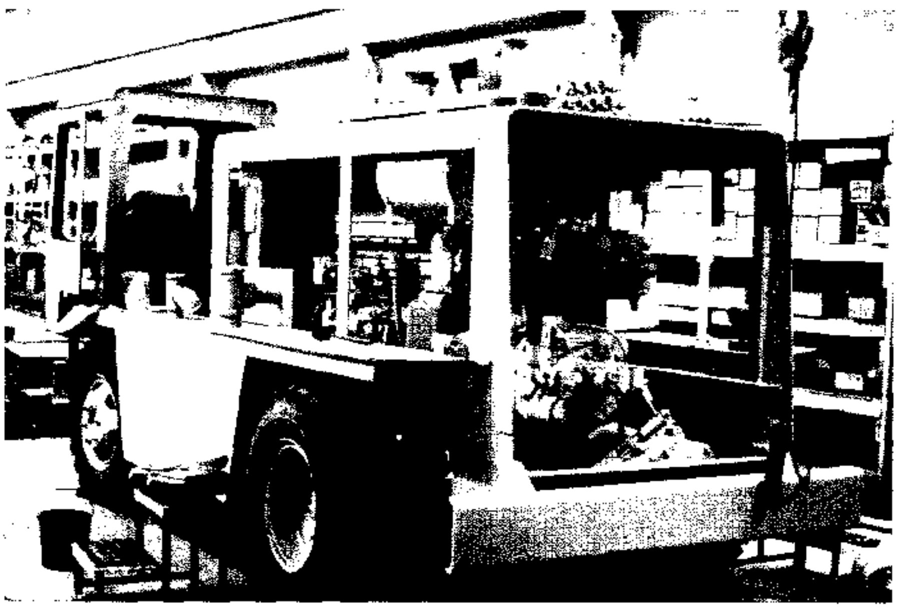
Backfill materials for underground cable

Phase I of a project at the University of California at Berkeley (UCB) was the evaluation of alternative backfill materials for underground cable trenches (RP7841). Various additives were mixed with existing soils to improve thermal performance. Phase II, which is under way, involves the long-term field testing of soils that have been mixed with the most promising of these additives. The most successful additive found was slack wax, a cheap by-product of petroleum refining.

Ten sections of pipe containing heaters to simulate cable losses were buried in an outdoor test environment. Thermal needles (developed by UCB) and moisture probes were positioned around the pipes to detect changes in heat transfer and rate of moisture migration.

Three-dimensional thermal profiles will be obtained for each trench and will be compared with mathematical solutions obtained by computer analysis. The wax backfill additive will be tested for effects of

Figure 4 Water-jet concrete-cutting hydraulic system mounted on a truck. This prototype will be circulated to four host utilities for evaluation and cost analysis.



various cyclic events, such as freeze-thaw, heating-cooling, water percolation, and compression-release. The in situ soil at the field test site has been analyzed for basic type, water table depth, grain variation with depth, and native thermal resistivity. These tests will indicate whether common in situ soils are thermally compatible with the proposed backfills. *Project Manager: Thomas Rodenbaugh*

Measuring thermal resistivity and soil stability

Ontario Hydro is conducting research to develop an improved thermal probe for in situ measurement of soil parameters (RP7861). This probe could be used along a cable route to classify the soil and determine its thermal characteristics in terms of thermal resistivity, stability, relative moisture content, and diffusivity. Load cycle forecasting and the establishment of maximum allowable temperature excursions would result from these measurements. The probe will also help utilities determine where special cable backfills are needed.

Present work focuses on characterizing soils by investigating their dielectric constants, temperature, moisture content, and dispersion as a function of frequency. These data will be useful in determining the range of frequencies at which the probe will accurately measure moisture flow in the soil during thermal cycling. It has been determined that moisture in clay-type soils can be determined most accurately at a setting of 0.5 MHz.

Other work in this project concerns thermal diffusivity in soils. Mathematical models are being developed to define soil diffusivity and describe how thermal conductivity profiles in soil vary as a function of moisture content and moisture gradients. Microprocessor controls are being developed for the thermal probe while various data collection tests are under way. This microprocessing and data acquisition system will be used to analyze the input from the probe while the probe is in the soil. *Project Manager: Thomas Rodenbaugh*

Forced convective cooling of HPOF cables

A high-pressure oil-filled (HPOF), or pipe-type, cable system consists of a steel pipe through which three insulated cables have been pulled. The dielectric consists of paper tapes impregnated with oil and surrounded by a reservoir of oil in the pipe. By pumping this oil through the pipe and through a heat exchanger (oil refrigerator), a higher power capacity can be attained in the cable circuit.

Heat transfer in scale models of pipe-type cables was investigated to define forced-cooling parameters and heat transfer from the cable insulation to the oil. There was also study of the nonuniform temperature distribution (hot spots) around cables in pipes placed in various geometries and of methods to eliminate the hot spots.

In a continuing effort to understand flow parameters and heating effects in pipe-type systems, the University of Illinois modeled and analyzed joints, cable snaking (thermal-mechanical bending), and entrance-exit effects on fluid and thermal parameters (RP7853). These three regions can account for a large percentage of the overall oil-flow pressure drop in a cable system. It was also found that these regions cause turbulence, which prevents fully-developed oil flow.

The snaking studies revealed much larger oil-flow pressure drops as a result of turbulence than were encountered with normal straight-cable configurations. Fully developed flow around bent cable is not regained for a distance equal to 100 times the diameter of the open area around the cable obstruction. This same effect takes place around the splices of the cable but to a lesser degree. Studies of the problems associated with snaking are continuing. Correlated work on roughness area ratios and their effects on laminar-turbulent flow patterns are also under way. *Project Manager: Thomas Rodenbaugh*

Improvement in extruded dielectric transmission cable

The investigations reported in EPRI Final Report TD-136, April 1976, indicated that microporosity occurring in the insulation of extruded dielectric cables has a significant influence on the performance of the insulation. This earlier work also showed that substantial improvements in the dielectric strength of the insulation could be achieved by impregnating the microporous regions with various fluids.

One of the advantages that extruded dielectric cable has over HPOF paper-insulated cable is simplicity of installation. Since extruded dielectric cable does not need to operate in a high-pressure fluid ambient, pressurizing and fluid storage systems are not needed.

In order to retain the simplicity of extruded cable installations while gaining the dielectric improvements attainable through impregnation, a project was instituted to investigate the possibility of impregnating extruded dielectrics with fluids that would stay fixed within the dielectric through polymerization (RP7854). Several promising impregnants and polymerizers have been identified, and work is progressing on miniature cable models. *Project Manager: Felipe Garcia*

SUBSTATIONS

SF_6 in oil

A project at Westinghouse Electric Corp. is designed to investigate the possibility of substituting SF_6 or a fluorocarbon gas (C_2F_6) for nitrogen in the region above the oil in oil-filled transformers (RP808). SF_6 and C_2F_6 have been used as dielectrics in electrical equipment but not as insulating gases in contact with and absorbed by transformer oils. There has been concern that the absorbed gas might be detrimental to the dielectric integrity of the transformer, especially if the absorbed gas disassociates from the oil as it discharges from the bottom of the coolers and enters the bottom section of the transformer. The project goals are to:

- Determine whether superior or inferior dielectric properties might result from the substitution of dielectric gases for the nitrogen gas normally used. Since SF_6 has superior dielectric strength as an insulation medium in the absence of oil, it is not unreasonable to anticipate improved properties with oil. C_2F_6 gas is also of interest.

- Determine whether leaks of dielectric gas into transformer oil (from gas-insulated substations) represent a potential source of concern

- Determine whether complex, double-flanged bushings could be eliminated at the junction between the transformer and the gas-insulated bus to increase economy

The three goals are obviously interrelated. If such a test program demonstrates that SF_6 provides superior dielectric properties, then one might anticipate no potential problems in the other two areas. On the other hand, if there are dielectric problems, their magnitude would determine whether gas leaks or loss of the double-flanged barrier would be a concern. The limited information available in the published literature is somewhat contradictory and of little value.

To answer the above questions, a series of tests evaluating absorbed-gas dielectrics, solubility, chemical compatibility, and long-term stability were planned. Dielectric tests included both 60-Hz and impulse voltages under uniform and nonuniform fields. Also included were dielectric breakdown tests in the presence of bubbles of the two experimental gases.

Arc and corona tests in oils with absorbed gases were performed. Compatibility tests involved the solubility of these gases in transformer dielectric materials. Stability tests were conducted for several thousand hours to determine effects on life tests of experimental 25-kVA transformers.

As with most research programs, some questions have been answered and a number of new ones have been raised. Solubility data show that the three gases behave quite differently in naphthenic transformer oil. The solubilities increase in moving from N_2 to SF_6 to C_2F_6, with ratios at 101 kPa (1 atm) and 27°C of approximately 1.0, 5.7, and 8.9, respectively. The change in solubility with pressure is linear for SF_6 and N_2 but not for C_2F_6. Other limited test data (e.g., from Pirelli testing) indicate that naphthenic and paraffinic oils appear to respond similarly when impregnated with the different gases. (Pirelli testing is a technique employed to ascertain whether gases have a tendency to be absorbed or evolved from the oil under stress.)

Regardless of the solubility differences, breakdown data employing the substitute gases have demonstrated that the gas nature has only a small influence on the results; SF_6 and C_2F_6 appear to neither enhance nor harm ac or impulse strength. Table 1 represents the average of various test results.

Interestingly enough, limited breakdown testing suggests that the presence of SF_6 bubbles is not harmful to dielectric strength but perhaps slightly beneficial. Pirelli testing indicated that SF_6 is strongly evolved from the mixture. C_2F_6 is absorbed, and N_2 is evolved, but at slow rates. The gas evolution may be potentially harmful in transformers. Recently, evidence has accumulated that under discharge, decomposition of SF_6 takes place (as it does in the absence of oil), which may be influencing test transformer behavior. In the stability tests, the two SF_6, 25-kVA test distribution transformers. while responding well initially, have required continuous venting at regular intervals beyond 500 hours. One of the two has failed for unexplained reasons. The two transformers with C_2F_6 have responded more satisfactorily. Testing and data collection will continue.

Results of solubility tests are encouraging. No significantly harmful effects have been observed when comparing the effects of SF_6 or C_2F_6 with those of N_2.

The questions contained in the three goals can now be partially answered.

- Absorption of SF_6 or C_2F_6 gas by oil does not impart superior properties to transformers. However, preliminary evidence of different breakdown responses during bubbling raises questions about the influence of the gases at the electrode site during breakdown.

- The life tests with SF_6 (which included an unanticipated failure) have indicated that chemical changes take place. It is not yet possible to determine whether SF_6 leaks are harmful over extended time intervals.

- Evidence suggests that double-flanged bushings should not be eliminated solely on the basis of the data collected in this project.

Long-term testing of 25-kVA distribution transformers is still in progess.

Although new questions have arisen, many of the questions that existed prior to this program can now be answered more definitely. *Project Manager: Bruce Bernstein*

Table 1
BREAKDOWN VALUES FOR NITROGEN AND OTHER GASES IN OIL
(kV)

	Nonuniform Field (point to plane*)		Uniform Field (2.5-cm spheres*)	
Dielectric	60 Hz	Impulse	60 Hz	Impulse
Gas				
SF_6	21	54	44	114
C_2F_6	22	60	39	119
N_2	25	57	31	130
Degassed oil	30	62	41	136

*0.254-cm gap.

Gases superior to SF_6

SF_6 gas is used extensively in circuit breakers because of its excellent arc-interrupting properties. Since SF_6 has a high dielectric strength, it is also used as a dielectric in gas-insulated transmission lines and compact substations, where it accounts for a significant fraction of the cost. Although SF_6 is a satisfactory gaseous dielectric in many respects (high dielectric strength, low toxicity, high stability, high compatibility), it also has certain drawbacks (e.g., susceptibility to electric breakdown in local nonuniform fields and when small conducting particles are present). Accordingly, Westinghouse, with E.I. du Pont de Nemours & Co., Inc., as a subcontractor, is performing a 30-month study designed to identify and test alternative gases or gas mixtures that might be superior to SF_6 (RP847).

While gases for use in circuit breakers need to have a high-power arc-interrupting ability, properties for both insulation and interruption applications are similar in many aspects, such as dielectric strength, thermal conductivity and chemical stability. However, since much larger quantities of gas are needed for gas-insulated equipment than for circuit breakers, economic factors can differ. Also, since gas decomposition will occur in arcs, the chemical stability can differ for the two applications.

The Westinghouse study consists of five phases.

- Literature survey and screening
- Experimental screening for dielectric, arc interruption, stability, and compatibility properties
- Theoretical development based on experimental data obtained
- Synthesis of promising gases
- Testing of novel gases or gas mixtures

The literature survey involved tabulation of all known gases with boiling points of less than $-10°C$ at atmospheric pressure. A practical gas or gas mixture must not condense at a temperature above $-30°C$ or $-40°C$, depending on the service conditions, and a gas with a boiling point below $-19°C$ can therefore be a major constituent of a practical gas mixture. The screening process involved an evaluation of available information on toxicity, flammability, dielectric strength, chemical stability, and compatibility. The gases were divided into three groups: 9 categories of inorganics, 10 categories of organics, and volatile liquids.

Via this process, the known gases with boiling points of less than $-10°C$ were reduced to 40 gases of further interest. Experimental evaluation of these is in progress.

The literature survey also included tabulation of a number of compounds with boiling points higher than $-10°C$, and from these were selected a group of possible components (defined as 10% or less of a mixture) that could improve the performance of a gas mixture.

From the information developed to date, it appears unlikely that any single gas will have properties that would allow it to be used as a direct substitute for SF_6. However, a number of gases appear suitable for mixtures, probably with SF_6 as a major constituent. Westinghouse will be evaluating about 30 gas mixtures for insulation and interruption applications. The literature survey also revealed that several gases that are not commercially available deserve consideration. Two of these gases will be synthesized and evaluated experimentally. *Project Manager: Bruce Bernstein*

Ice release coating for air-break switches

Ice buildup on outdoor disconnect switches has been a severe deterrent to satisfactory remote or automatic operation. Clear ice buildup can develop under certain atmospheric conditions and lead to incomplete operation. To cope with this problem, disconnect switch designs employ powerful operating mechanisms and expensive high-strength switch components.

To address this problem, a project has been initiated with Siemens-Allis Corp. to explore the use of thin-film coatings to minimize ice adhesion (RP931). The objective of this project is to determine if inexpensive, commercially available coating material with a low coefficient of friction under ice can be used on standard disconnect switches to reduce ice adhesion and buildup and release the ice during the closing and opening operations (Figure 5).

Under Phase I of this project, eight different coating materials were selected for a comprehensive test and evaluation program. A coating material has been selected that reduces ice adhesion by a factor of 6. This coating also enhances heat dissipation, promising a cooler operating switch.

The second phase of this project will test both copper and aluminum switches coated with this material and operated under ice conditions in a laboratory. *Project Manager: Vasu Tahiliani*

DISTRIBUTION

Boring equipment

There are approximately 200,000 conductor miles of underground residential distribution cable in service in the United States.

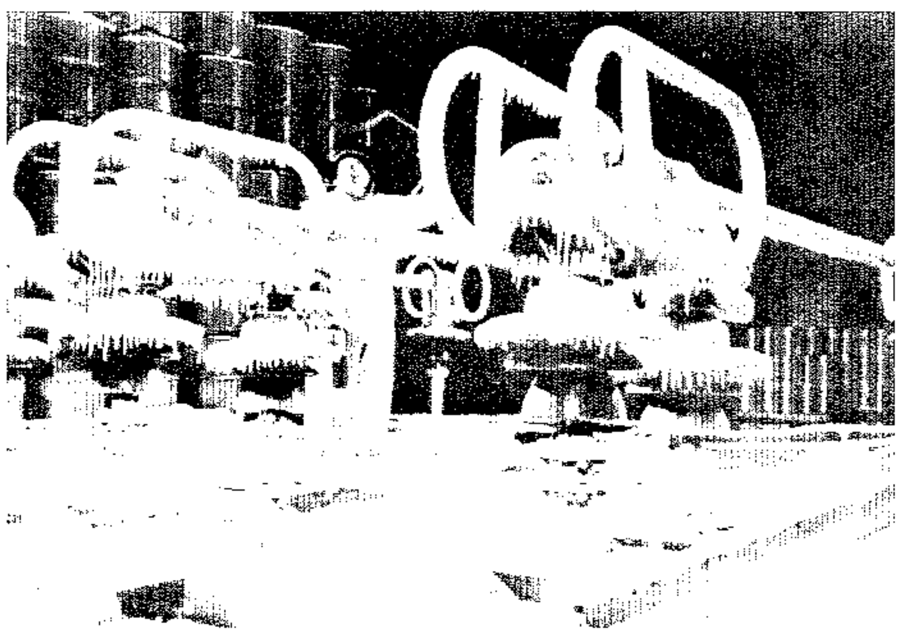


Figure 5 A 500-kV disconnect switch under test to evaluate switching performance during ice buildup.

This cable will eventually have to be replaced because of deterioration or obsolescence. Replacement in developed areas by present trenching and backfill methods would be very expensive.

Boring is an alternative method of installing and replacing underground distribution cables and conduits. However, because of economics, poor accuracy (which limits length of bore), and the excessive time needed to complete a successful bore, only about 1–2% of underground distribution construction is installed by boring.

Development of an improved boring system for small bores (5–15 cm; 2–6 in) is needed in order to provide a practical and economical alternative to the trench-and-backfill method now used in developed areas. EPRI has therefore initiated a four-year project with Flow Industries, Inc., to develop and test improved boring equipment (RP1287). *Project Manager: Thomas Kendrew*

High-impedance faults

The current that flows during a fault depends on a number of variables, one of which is the impedance of the condition that creates the fault. High impedance at this point can limit the fault current to values that are below the level of operation of the fault-clearing device, and thus the fault condition persists because it cannot be recognized as a fault. An example of such a fault is when a phase conductor of a grounded wye system breaks and contacts the earth at a relatively nonconductive point, such as on a macadam street. In this case, the current that flows between phase conductor and ground may be limited to a few amperes. This condition cannot be recognized by conventional fault-clearing devices, and the conductor remains energized, thereby presenting a safety hazard to anyone who might touch it. The complexity of this problem has suggested a parallel effort by three contractors. Power Technologies, Inc., in a comprehensive study of the electrical behavior of high-impedance faults, will aim at identifying characteristic parameters and will also develop specifications for a detection instrument (RP1285-1). Hughes Research Laboratories (RP1285-2) and Texas A&M University (RP1285-3) will each continue studies of existing detection concepts and will develop prototype detection instruments if these concepts prove feasible. *Project Manager: Herbert Songster*

Water treeing

One of the apparent causes of failure in electrical cables is a phenomenon called water (or electrochemical) treeing. Although the phenomenon has been studied in depth in the United States, Europe, and Japan, the causes and preventatives are not yet fully understood. A recently completed EPRI project developed a substantial amount of data on factors that influence inception and growth of such trees (RP133). The work was performed on small laboratory samples of insulated wire (#12 AWG). Evidence has also been accumulated indicating that the development of these trees reduces the useful life of a cable.

Another EPRI project, with Phelps Dodge Cable & Wire Co., is designed to test full-size, 15-kV cables with high-molecular-weight polyethylene insulation in order to predict remaining useful life (RP1357). Trees will be developed in freshly prepared cable by using accelerated stresses (voltage, frequency). The effect of such trees on dielectric properties will be established. Older cables, some aged in service and others stored by utilities but never energized, will be tested concurrently. They will be subjected to the same accelerated stresses as the freshly prepared cables. Tree penetration in the "field-aged" cables, "field-unaged" cables, and freshly prepared cables will be compared. By assuming that similar treeing responses can be obtained after different aging times under identical accelerated conditions, the difference between "good" and "bad" cable will be sought. In the three-year test, cables will be aged, tested, and microscopically evaluated. A statistical evaluation of the data will then be performed. *Project Manager: Bruce Bernstein*

Fault currents

The objective of a project being carried out by Power Technologies is to make available to utilities comprehensive statistical data on fault currents as they are actually experienced on primary distribution systems (RP1209). The continuing growth in electricity demand has made it necessary to increase the size of all system components. This, in turn, has caused a marked increase in fault current duty on all system equipment—a matter of considerable concern.

Reliable data to establish the actual values of fault currents experienced are not available. While it is well known that almost all faults produce currents below calculated values, the actual magnitudes, fault characteristics, and frequency of occurrence are not generally known. The lack of this type of test data results in imprecise system design, incorrect selection of equipment, and a strong tendency toward conservative application.

This three-year research project on fault current analysis is being undertaken to improve knowledge of the electrical and statistical parameters associated with faults on utilities' distribution systems. *Project Manager: Herbert Songster*

OVERHEAD LINES

Wind-induced conductor motion

Countless man-hours are spent by transmission design engineers in an effort to keep up with, evaluate, and use the fragmented published information on wind-induced conductor motion. Collecting this information is even more difficult for the engineer just entering the field. An EPRI-funded project on wind-induced conductor motion will soon provide a transmission line reference book that will organize the information in one volume (RP792).

The book can be used by utility transmission design and operating personnel as a reference and design book on wind-induced conductor motion problems. Subjects include aeolian vibration, galloping, fatigue, and wake-induced oscillation. Each problem will be discussed as to background, causes, and practical solutions. Various contractors will contribute different chapters of the book, with Commonwealth Associates Inc. writing the introduction and serving as editor. Alcoa Conductor Products Co. has responsibility for the chapters on galloping and conductor fatigue and shares responsibility with Boeing Engineering & Construction for the chapter on wake-induced oscillation. Washington State University has prepared the chapter on aeolian vibration (Figure 6).

The book, which is the fourth in a series of EPRI transmission line reference books, should be available in late 1978. *EPRI Project Manager: Mike Silva*

Figure 6 This severe conductor fatigue damage was caused by aeolian vibration. Both conductor fatigue and aeolian vibration will be covered in a transmission line reference book on wind-induced conductor motion, to be published later this year.

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

WASTE HEAT UTILIZATION

One part of EPRI's research on waste heat utilization is a joint effort with Tennessee Valley Authority (TVA) to collect and review available information on the subject (TPS77-700). Of particular interest is the interfacing of waste heat utilization systems with power plant cooling systems.

The Ecological Effects Program shares responsibility for research into waste heat utilization with two programs in the Fossil Fuel and Advanced Systems Division—the Energy Utilization and Conservation Technology (EUCT) Program and the Water Quality Control and Heat Rejection Program. The EUCT staff is studying waste heat utilization as part of its evaluation of dual energy use systems (EM-718-SR). The Water Quality Control and Heat Rejection Program staff is interested in the engineering aspects of integrating waste heat utilization systems with power plant cooling systems. Although the two programs are not taking part in the EPRI–TVA information study in order to avoid duplication of effort, they were nevertheless involved in the initial planning and are actively monitoring the progress of the project.

In the first phase of the effort, a state-of-the-art document on waste heat utilization in agriculture and aquaculture was developed by staff from TVA's Agricultural Development Division; Forestry, Fisheries, and Wildlife Development Division; and Energy Research Division. This comprehensive document is the product of an extensive literature review and visits to sites of waste heat utilization projects throughout the United States. Table 1 lists some of the waste heat utilization projects that involve utilities and are covered by the report.

Among other topics, the report describes several ways of integrating research and commercial waste heat utilization systems with power plant cooling systems. One approach, which is used in aquaculture, is to place culture cages, floats, and pens in discharge canals and lagoons. This method is in use at generating stations operated by Texas Electric Service Co., Long Island Lighting Co., and Central Maine Power Co. Another approach is to pump water from discharge structures and canals to an outside

Table 1
PROJECTS ON WASTE HEAT UTILIZATION INVOLVING UTILITIES

Project	Contractors	Locations
Aquaculture		
Demonstration-scale culture of rainbow trout	Public Service Electric and Gas Co., Trenton State College, Rutgers University, Long Island Oyster Farms	Mercer Generating Station
Pilot-scale culture of freshwater shrimp, American eels, and striped bass	Public Service Electric and Gas Co., Trenton State College, Rutgers University, Long Island Oyster Farms	Mercer Generating Station
Pilot-scale culture of lobster	San Diego Gas & Electric Co., Southern California Edison Co., San Diego State University	Encina Power Plant, Redondo Beach Generating Station, Ormond Beach Generating Station
Pilot-scale culture of catfish	Tennessee Valley Authority	Gallatin Steam Plant
Agriculture		
Research and commercial greenhouses	Northern States Power Co., University of Minnesota	Sherburne County Power Plant
Demonstration greenhouse (under construction)	Tennessee Valley Authority	Browns Ferry Nuclear Power Plant
Pilot-scale greenhouse	Public Service Electric and Gas Co., Rutgers University	Mercer Generating Station

user. Utilities that have made such an arrangement include Public Service Electric and Gas Co., Southern California Edison Co., and TVA. Neither approach has much effect on the operation of cooling systems, unless the utility and the user make special arrangements relating to chemical treatment of cooling water. Users generally take water in the condition in which it is discharged during normal plant operation and then adjust their cultural procedures to existing water temperatures and flow rates.

Waste heat utilization systems have also been installed at power plants that have cooling towers. One of Northern States Power Co.'s plants has a waste heat delivery system that extracts warm water from a cooling-tower riser and supplies it to research and commercial greenhouses. In this case also, the waste heat users accept water from normal generating operations, and the amount of water that is used has little, if any, effect on operation of the cooling tower or on power production. Factors identified as being of primary interest to a utility evaluating a potential agreement with a waste heat user include:

- Investment and construction requirements for waste heat supply systems
- Degree and reliability of cooling by the user when a closed cycle is in use
- Establishment of policies and costs for making waste heat (and possibly utility-owned land) available to users
- Possible effects on electricity production
- Possible effects on plant safety and security
- Applicable state and federal regulations

Factors considered to be of primary importance to the waste heat user include:

- Temperature and quality of water
- Reliability of source and need for backup systems
- Costs of waste heat delivery and use systems (including charges by utilities for waste heat and/or land)
- Location requirements for user's site
- Labor costs of construction and operation
- Marketability and public acceptance of products

The first phase of the joint EPRI–TVA effort has focused primarily on the state of the art of utilization technologies. The work on interfacing waste heat utilization systems with power plant cooling operations has been preliminary and will be pursued in greater depth in late November at a joint EPRI–TVA workshop on factors affecting power plant waste heat utilization (WS77-27). Participants will include representatives of the electric power industry, the waste heat user community, and various federal agencies, such as the Environmental Protection Agency, the Food and Drug Administration, Nuclear Regulatory Commission, Department of Energy, and Department of Commerce. The overall objective of the workshop is to describe and analyze problems that have to be resolved both by the utilities that supply waste heat and by the users of waste heat. Waste heat utilization technology will be discussed briefly, but the primary emphasis will be on such topics as legislation affecting waste heat utilization, problems related to waste heat utilization at nuclear power plants, and utility charter constraints on waste heat utilization. *Project Manager: Robert Kawaratani*

ELECTRIC UTILITY RATE DESIGN STUDY

The Electric Utility Rate Design Study (RP434) has produced approximately 50 research reports on various aspects of load management for the National Association of Regulatory Utility Commissioners (NARUC). Additional research on time-differentiated rates and load controls has begun in 1978 and is organized into four major topics: (1) costing, rate design, and elasticity, (2) load controls and equipment for using off peak energy, (3) customer response, and (4) cost-benefit analysis.

The Rate Design Study has completed its second year with the submission of a major report to NARUC in November 1977. The report, *Rate Design and Load Control: Issues and Directions,* summarizes the findings of two years' research and discusses the need for further research. State regulatory commissions and individual utilities are encouraged to study the research results and use them in formulating their own cost-effectiveness studies of time-differentiated rates and load controls.

As discussed in the *Guide To Electric Utility Rate Design Study Reports*, some 50 reports have been prepared by several consultants for the Rate Design Study, in part to comply with NARUC's request for research on slowing the growth in peak demand and shifting electrical loads from peak to off-peak periods. These reports have been distributed to state regulatory commissions and utilities.

As specified in the *1978 Plan of Study,* additional research is organized under four major topics. Topic 1, which has the broadest scope, is divided into three major categories: estimation of elasticities by time of use, calculation of costs and rates, and cataloging of load research data. The general objective of the research on elasticity is to improve the ability of individual utilities to estimate loads as functions of time when time-differentiated rates are in effect. Research on calculation of costs and rates includes:

- Evaluation of various marginal-costing procedures
- Adjustment of marginal costs to form rates
- The "second best" issue (relationship of energy prices to marginal costs)
- Allocation of costs for time-differentiated rates that are based on accounting costs
- Evaluation of the process for selecting rating periods
- Analysis of block-rate structures

The primary objective of the work on load research is to develop a comprehensive and accessible catalog of studies on load shapes categorized according to specific appliances, locations, and other characteristics. The Association of Edison Illuminating Companies is cooperating in this effort.

Topic 2 evaluates equipment to be used with time-differentiated rates and load controls. The research includes an analysis of a sample of 16 established or experimental load management programs of representative interest and an analysis of the need for additional information on load management equipment.

Topic 3 evaluates customer reaction to load controls and time-differentiated rates from a motivational rather than econometric standpoint. The implementation of this research relies heavily on a series of customer surveys. One set of surveys concerns general public awareness and understanding of the concepts and terminology that pertain to load management and rate structure. A second set of surveys addresses customer reaction to mandatory changes in rate structure and load control.

The main objective of the research in Topic 4 is to refine and develop procedures and models for estimating the benefits and costs of various load management strategies. The research evaluation includes the study of three concerns: (1) changes in the costs of providing electric service to the customers' premises, (2) changes in the costs of using electric services at the customers' premises, and (3) impacts of load management on society. *Project Manager: Robert Malko*

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 10090, Palo Alto, California 94303; (415) 961-9043. 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 pay a small charge. Research Reports Center will send a catalog and price list on request.

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

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

ELECTRICAL SYSTEMS

Theory and Design of a Brushless Superconducting Alternator

EL-479 Final Report (RP563-1)

The objective of this project by Case Western Reserve University was to demonstrate the feasibility of constructing and operating a brushless superconducting generator. In this machine a flux pump would indirectly couple electric energy into a superconducting rotor, thus eliminating the need for current leads and brushes or slip rings. The demonstration unit was to be rated at 1 kVA with an open-circuit voltage of 50 kV.

None of the desired machine parameters were obtained because numerous technical difficulties prevented the machine from being run successfully. Nevertheless, a theoretical design for a suitable flux pump was developed. *EPRI Project Manager: Mario Rabinowitz*

Improvement of Electrical Porcelain Insulators

EL-721-SY Final Report (RP424-1)

An in-depth study by Gould Inc. of four types of porcelain presently used for electric power insulation provided insight into the mechanisms that determine and limit their strength. Various raw materials potentially suitable for porcelain compositions were investigated to see if their use would strengthen the porcelain without reducing adaptability. Improved processing techniques and changes in composition yielded new porcelains having mechanical strengths much greater than those of commercial porcelains. This development will add flexibility to the design of electrical systems. For example, insulator strings may carry larger conductors, thereby increasing transmission capacity at existing voltages, and in station applications, insulators with higher resistance to short-circuit forces may be available. *EPRI Project Manager: E. R. Perry*

Light-Fired Thyristor Development

EL-776 Interim Report (RP567-1)

A high-power, light-triggered thyristor has been developed and demonstrated by Westinghouse Electric Corp. Eight of these thyristors connected in series were tested to show feasibility for commercial utility applications with VAR generators.

The chief benefit of light-triggered thyristors is that a high-voltage stack of them can be switched directly by a light signal transmitted through electrically insulating fiber optic cables. Such a system eliminates the need for costly isolation of the gate circuitry and provides immunity against noise-induced false triggering signals. *EPRI Project Manager: Stig Nilsson*

Electrostatic and Electromagnetic Effects of Ultrahigh-Voltage Transmission Lines

EL-802 Final Report (RP566-1)

General Electric Co. carried out research on electric and magnetic field effects of high-voltage ac power lines at EPRI's Project UHV from January 1974 to December 1977. Electrical rather than biological research was performed and applied to UHV and EHV transmission lines. Calculation methods and measuring techniques were developed for transmission line fields and their effects. Steady-state and spark discharge currents induced in persons and objects were investigated with laboratory and full-scale tests using a three-phase UHV line. *EPRI Project Manager: Frank Young*

Development of Distribution and Subtransmission SF_6 Circuit Breaker and Hybrid Transmission Interrupter

EL-810 Final Report (RP661-1)

This project by I-T-E Imperial Corp., a subsidiary of Gould Inc., covered the development of a new SF_6 arc spinner interrupter and a 15-kV circuit breaker (distribution) using this interrupter. It also investigated the feasibility of a high-voltage hybrid interrupter (transmission) using the arc spinner and a vacuum interrupter in series.

The arc spinner interrupter uses a self-generated magnetic field to drive an arc on a circular path in an atmosphere of SF_6 gas to achieve interruption.

In the hybrid interrupter, the vacuum interrupter handles the high initial rate of rise in recovery voltage associated with short-line faults, and the arc spinner interrupter handles the high peak transient recovery voltage. *EPRI Project Manager: William Shula*

ENERGY ANALYSIS AND ENVIRONMENT

The Stanford PILOT Energy-Economic Model

EA-626 Interim Report, Vols. 1 and 2 (RP652-1)

PILOT is a U.S. national energy-economic model that compares various policy decisions by measuring their impacts on the standard of living. Through its dynamic linear programming formulation, the modeled economy allocates industrial output to consumption and to capital formation in the current period to achieve the highest standard of living over the planning period. The "take home" (consumption) income is used to measure the standard of living.

Three sets of input conditions are used to illustrate the model's behavior and capabilities. The assumptions for the base case and two variations were developed by Stanford University in consultation with EPRI. One variation assumes a higher availability of primary energy than the base case, the other a lower availability. *EPRI Project Managers: Richard Richels and Oliver Yu*

Supply 77: EPRI Annual Energy Supply Forecasts

EA-634-SR Special Report

In this study, domestic energy production and prices by fuel type, as well as imports, were projected for the 1975–2000 period. Natural gas production is expected to increase gradually to 1990 and then decline. Output of domestic petroleum liquids, including shale oil, may peak in the 1990–1995 period and then decline. Shale oil output may reach 1 million bbl/d by the end of the century. Coal production capability is expected to increase throughout the period, reaching 2.6 billion t/yr by 2000, provided that markets develop for this output. Nuclear power could grow at an accelerated rate, with output reaching 380 GW in the year 2000. At this level, nuclear power would produce as much electricity as the burning of an additional 1.3 billion tons of coal. *EPRI Project Manager: Milton Searl*

Effects of Risk on Prices and Quantities of Energy Supplies

EA-700 Final Report,
Vols. 1, 2, 3, and 4 (RP869-1)

Volume 1 summarizes the major findings of this study by MicroEconomic Associates, and Volume 2 gives an overview of the economics of uncertainty, a relatively new field, and its implications for energy supply. The presentation assumes a knowledge of the economic theory of production and consumption under conditions of certainty and an elementary familiarity with statistical techniques.

Volume 3 is a collection of surveys describing the application of the economics of uncertainty to the analysis of risk in particular components of the market for energy supplies.

Volume 4 contains a number of technical papers written in the course of this project. These present new results in particular areas of research. For example, two papers deal with the theory of contracting for research and development and address questions such as contractual incentives and the distribution of gains between contractor and contractee. *EPRI Project Manager: A. N. Halter*

Residential Demand for Electricity by Time of Day: An Econometric Approach

EA-704 Final Report (RP882-1)

To analyze the level and shape of the residential demand cycle for electricity, the University of Illinois used data from a time-of-day metering survey of residential electricity use and an FEA-sponsored peak-load-pricing field test conducted on randomly selected customers of The Connecticut Light and Power Co. The analysis estimates the impact of such factors as space heating, electric water heating, and stock of electrical appliances on the demand cycle. *EPRI Project Manager: Anthony Lawrence*

Foreign Uranium Supply

EA-725 Final Report (RP883)

NUS Corp. assessed the extent to which foreign uranium may be available to U.S. utilities in the short term (through 1980), the intermediate term (1981–1985), and the long term (1986–95). All free-world foreign uranium producers and prospects are taken into account, with particular emphasis on producers in Australia, Canada, southern Africa (Namibia and the Republic of South Africa), France, and French-speaking Africa. The assessment considers various factors that may influence access to and price of foreign uranium, including reserves, resources, exploration, and prospects; firm and potential production capacity; national policies and relevant political and economic conditions; and foreign uranium demand. *EPRI Project Manager: Jeremy Platt*

The Outlook for World Oil Into the Twenty-first Century

EA-745 Final Report (SOA-76-326)

This study by Petroleum Industry Research Foundation, Inc., attempts to forecast oil supply and demand in the free world for two periods: 1976–1990 and 1990–2005. It treats oil as the energy supply of last resort and places special emphasis on oil from the Organization of Petroleum Exporting Countries (OPEC).

First the researchers project energy demand on the basis of forecasted economic growth rates and energy-economy growth relationships. They assume that this demand will be met to the maximum feasible extent from nonoil energy supplies, including coal, gas, nuclear power, and hydro and geothermal power. The total oil demand that remains is met first with non-OPEC oil supplies in order to test the demand for, and the adequacy of, OPEC oil supplies under different energy demand scenarios.

The study concludes that a gradual transition to nonoil sources of energy over the next 25 30 years is more likely than an extended oil shortage of crisis proportions. *EPRI Project Manager: Thomas Browne*

Water Supply Data Base System

EA-790-SY Summary Report (RP762)

This study by the University of Arizona has produced a data base, or "data dictionary," that describes efforts to collect data on water supply. The system has two components, a macro data base and a micro data base. The first contains an overview of regions, organizations, and data sets and their interrelationships; the second gives the detailed structure of each data set. National data and Colorado River Basin data are included. The data bases are currently installed on a commercial computer that is accessible through a national communication network. *EPRI Project Manager: Rex Riley*

Load and Use Characteristics of Electric Heat Pumps in Single-Family Residences

EA-793 Final Report, Vols. 1 and 2 (RP432-1)

This joint EPRI–AEIC project was initiated to obtain information on the operation of heat pumps in residential heating systems. In field tests using magnetic tape recording equipment, Westinghouse Electric Corp. recorded heat pump and total house electric energy usage every 15 minutes in 120 installations in 12 geographic regions. *EPRI Project Manager: Robert Crow*

Workshop Proceedings: Environmental and Social Impacts of an Electricity Shortage

EA-796-SR Special Report (WS-77-24)

This report by Sigma Research, Inc., presents the papers and summarizes the conclusions of a workshop on the environmental and socioeconomic impacts of electricity shortages. The workshop reviewed the results of past research, attempted to put the problem in perspective, and identified research needs. *EPRI Project Manager: Ronald Wyzga*

Applicability of Brookhaven National Laboratory's Energy Models to Electric Utility R&D Planning

EA-807 Final Report (RP873)

This study by Systems Control, Inc., evaluates Brookhaven National Laboratory's energy optimization models BESOM and DESOM with respect to their suitability for use by the electric utility industry as R&D planning aids. It finds that although the models provide some insight into the interactions of the energy system, they lack a detailed representation of the electric energy subsystem and hence are not suitable for detailed electric utility studies. Several modifications are suggested to improve the models' representation of the electric energy system. *EPRI Project Manager: Jerome Karaganis*

FOSSIL FUEL AND ADVANCED SYSTEMS

Design of Alloys Resistant to High-Temperature Corrosion-Erosion in Coal Conversion Environments

FP-557 Interim Report (RP589-1)

The state of the art and science of design of alloys that are resistant to high-temperature erosion-corrosion in coal conversion environments has been critically reviewed by Battelle, Columbus Laboratories. It is concluded that the state of the art of the application of wear-resistant alloys in a large number of corrosive environments is good, in that workable solutions to problems can usually be found. However, since these solutions involve modifying the environment by redesign, where possible, to minimize the erosive-wear or corrosion factors, and since the choice of resistant alloys is based on previous experience or trial and error, the state of the science appears to be poor. This is so mainly because there is no acceptable correlation of alloy erosion behavior with alloy properties or microstructure, and there are few available descriptions of the mode of erosion of alloys.

Most erosion research has concentrated on severe conditions where erosion is linear with time and has found little difference in erosion rates among conventional alloys. Laboratory results suggest the existence of other modes of erosion (or deposition) under the less severe conditions expected in coal conversion reactors and in many transfer lines, so that in this area significant scope may exist for alloy design. Little is known about how erosion and corrosion interact, and few studies have been conducted of erosion under corrosive conditions. *EPRI Project Manager: Robert Jaffee*

Clean Distillate Fuels Pilot Plant: Conceptual Study

AF-622 Final Report (RP916)

This report by Foster Wheeler Energy Corp. presents the conceptual design of a pilot plant that would convert one ton of coal per hour to a clean distillate fuel and a methanol fuel, both suitable for gas turbines. Two hypothetical examples are given of sites where the pilot plant could be installed—one site that contains some of the required equipment and services at Texaco's Montebello (California) gasification pilot plant and another site that is suitable for a grass roots installation, such as Wilsonville (Alabama). Also, a number of alternatives are discussed, such as coal preparation, residue melting, Stretford sulfur removal, and methanol recycling. *EPRI Project Managers: Ronald Wolk and Howard Lebowitz*

Parameter Monitoring for Corrosion Control of Utility Gas Turbines

AF-665 Interim Report (RP643-1)

Hot corrosion is a significant durability-limiting factor in industrial gas turbine engines. It is caused primarily by alkali sulfates depositing on the turbine airfoils. The objective of this project by United Technologies Corp. was to determine from field and laboratory test data the conditions that cause deposition of these corrodents and to define an engine control system that would minimize their effect.

Field data on 600 engines were statistically analyzed to determine the influence on hot corrosion of fuel type, engine washing, air filtration, and the proximity of the engine sites to oceans. Laboratory tests are being conducted on turbine materials, with and without protective coatings, to assess relative resistance to corrosion. Corrosion rates in the presence of sodium sulfate alone and with carbon, vanadium, and lead are being defined. *EPRI Project Manager: Richard Duncan*

Liquid Phase Methanol

AF-693 Interim Report (RP317-2)

This report describes work by Chem Systems Inc. on the development of the liquid phase methanol process at laboratory, bench, and process development unit (PDU) scales.

The PDU work consisted of several five-day runs, the results of which demonstrate the basic operation of the process. The runs were clouded somewhat by catalyst deactivation. A long-term PDU demonstration is the major goal of the continuing program. *EPRI Project Managers: Howard Lebowitz and Ronald Wolk*

Study of the Deactivation of Methanol Synthesis Catalysts

AF-694 Final Report (RP779-12)

This report summarizes the progress made by Lehigh University on the study of the deactivation of methanol synthesis catalysts. It also presents a brief review of the commercial production of methanol, as well as a commentary on the use of methyl fuel by electric utilities. *EPRI Project Managers: Howard Lebowitz and Ronald Wolk*

Assessment of the Role of Advanced Technologies in Small Utilities

EM-696 Final Report, Vol. 2 (RP918)

Research and development efforts are being pursued for a number of advanced power generation technologies that have the potential to contribute to the national energy supply. Burns & McDonnell assessed the potential role of six of these technologies in small municipal and rural electric utility systems by comparing the economics of the advanced technologies with the economics of conventional generation types. *EPRI Project Manager: Arnold Fickett*

Workshop Proceedings: Dual Energy Use Systems

EM-718-W (WS-77-40)

Representatives from the electric utility industry, industrial and other consumer experts, government officials, academicians, and equipment manufacturers met at an EPRI-sponsored workshop on dual energy use systems (DEUS), held September 19–23, 1977, in Yarmouth, Maine. The workshop was designed to give participants an opportunity to discuss and evaluate various options for using thermal and electric energy produced from a common source. The application areas reviewed were district heating, cogeneration, use of power plant reject heat, total energy applications, and emerging technologies with potential for the simultaneous production of heat and power. *EPRI Project Manager: Deborah Dougherty*

Process Engineering Evaluations of Alternative Coal Liquefaction Concepts

AF-741 Final Report, Vol. 1, and Supplementary Report (RP411-1)

Process engineering evaluations were prepared by The Ralph M. Parsons Co. for two coal liquefaction concepts, the noncatalytic SRC process and a generic catalytic hydroliquefaction process. The evaluations were made within the framework of complete, self-sustained plants requiring only coal and water as feed materials. The engineering designs and capital cost estimates were developed for a southern Illinois location and used the same general process configuration and supporting units for both liquefaction systems. Since the designs are based on commercially demonstrated technology wherever possible, they can be used to assess the cost of a first-generation plant that could be constructed today. These initial designs are intended to be base cases for assessing the cost impact of process improvements that will be incorporated into subsequent designs.

The cost of on-site power generation appeared to represent a significant proportion of the overall plant capital cost. To assess the implication of this, two additional cases were developed using purchased power. These cases are based on the low-severity SRC process and are presented in the supplementary report. The use of purchased power can reduce the total plant investment by 12–17% and total manufacturing cost by 2–6%. *EPRI Project Managers: R. A. Loth and S. A. Vejtasa*

Biofuels: A Survey

ER-746-SR Special Report

Biofuels are fuels derived directly or indirectly from biomass (organic plant material). The production and collection of biomass and its use as, or conversion to, fuel are generally referred to as bioconversion. This survey discusses photosynthesis, plant productivity, waste and residue resources, energy farming, processes for using biomass directly or converting it to fuel, and overall economics. Current U.S. R&D programs and applications by U.S. industries and utilities are emphasized. *EPRI Project Manager: Edgar DeMeo*

EPRI Methodology for Preferred Solar Systems: Computer Program Documentation

ER-771 User's Guide (RP926)

In this project Arthur D. Little, Inc., continued development of a computer program for analyzing the behavior of residential solar heating and cooling systems. Unlike several other programs designed for this purpose, this program is capable of estimating the cost of backup electric energy from a utility's actual cost of supply as well as from its rate structures. This feature provides a unique capability for considering costs on both sides of the electric meter and thereby aids in identifying systems that meet the needs of both the consumer and the utility. *EPRI Project Manager: John Cummings*

Economic Evaluation of Fabric Filtration Versus Electrostatic Precipitation for Ultrahigh Particulate Collection Efficiency

FP-775 Final Report (RP834-1)

The relative economics of electrostatic precipitators and fabric filters were studied by Stearns-Roger, Inc., for a variety of U.S. coals. The more economical method in each case was found to depend on the particulate emission limit to be met, the physical and chemical characteristics of the coal and fly ash, and the bag replacement schedule for the fabric filter. The studies were based on a 500-MW pulverized-coal-fired power plant with a well-designed fly ash collector system of high reliability. *EPRI Project Manager: Donald Teixeira*

Gasification of Coal Liquefaction Residues From the Wilsonville SRC Pilot Plant Using the Texaco Coal Gasification Process

AF-777 Final Report (RP714-3)

High-ash residues resulting from the liquefaction of west Kentucky 9/14 coal with the SRC-I process were successfully gasified by Texaco, Inc., in a pilot-scale coal gasifier at 2400 kPa (24 atm).

Four sets of runs were completed using filter cake, high-ash solvent-refined coal, and Kentucky coal in various mixtures. *EPRI Project Manager: Ronald Wolk*

Short-Residence-Time Coal Liquefaction

AF-780 Final Report (RP779-5)

Battelle, Columbus Laboratories investigated coal liquefaction at short residence time using a laboratory-scale reactor to process west Kentucky 9/14 coal and recycle solvent from the Wilsonville SRC pilot plant. The effects of processing conditions—temperature, pressure, solvent/coal ratio, and residence time—on the initial dissolution of coals were studied. The effects of adding high-pressure molecular hydrogen and tetralin were also studied. *EPRI Project Manager: William Rovesti*

Liquid-Phase Prilling of Solvent-Refined Coal

AF-781 Final Report (RP779-9)

E. I. du Pont de Nemours & Co., Inc., demonstrated a process for solidifying solvent-refined coal (SRC) by injecting molten SRC into water to form hard prills (~5 mm diam) under conditions that should be attainable on a commercial scale. This report describes the experiments and presents a conceptual design and a research guidance estimate for a commercial facility capable of producing 226.8 Mg (250 U.S. tons) of SRC prills per hour. In addition, it presents recommendations for further development of the process. *EPRI Project Manager: Norman Stewart*

Economics of Fuel Gas From Coal: An Update Including the British Gas Corporation's Slagging Gasifier

AF-782 Final Report (RP239)

This report presents the results of an economic screening study by Fluor Engineers and Constructors, Inc., of British Gas Corp.'s oxygen-blown slagging coal gasification process for the production of intermediate-Btu fuel gas. Included is an update of the economics sections of an earlier report (AF-244), which covered air- and oxygen-blown versions of the Lurgi moving-bed process, the U-gas fluidized-bed process, and the Combustion Engineering entrained-bed process. *EPRI Project Manager: Michael Gluckman*

Economic Comparison of Hydrogen Production Using Sulfuric Acid Electrolysis and Sulfur-Cycle Water Decomposition

EM-789 Final Report (RP1086-2)

Westinghouse Electric Corp. evaluated the relative economics of two advanced techniques to produce hydrogen—the Westinghouse sulfur-cycle water decomposition system and a water electrolysis system using a sulfuric acid electrolyte. In the Westinghouse system, a hybrid system, hydrogen is produced in an electrolyzer that uses sulfur dioxide to depolarize the anode. *EPRI Project Manager: Arnold Fickett*

Coal Preparation for Combustion and Conversion

AF-791 Final Report (RP466-1)

This report by Gibbs & Hill, Inc., covers the full scope of coal processing, from mine face to post-combustion stack gas cleanup, and provides essential information for assessing the potential contribution of physical (as opposed to chemical) coal beneficiation to a utility's fuel procurement and utilization strategy. *EPRI Project Manager: Richard Schmidt*

Hot Water System Efficiency Study at South County Hospital, Wakefield, Rhode Island

ER-794 Interim Report (RP554-1)

Daystar Corp. installed a solar-electric domestic water heating system at South County Hospital, Wakefield, Rhode Island, in 1975. Initial performance measurements showed that the overall system efficiency was approximately 35%. To deliver one unit of hot water at the faucet required three units of energy input. This study was undertaken to identify the losses that caused this low efficiency and to suggest improvements in the South County installation and future similar installations. *EPRI Project Manager: Gary Purcell*

Fault Tree Analysis for Reliability Prediction of Gas-Turbine-Type Power Plants
AF 811 Final Report (TPS77-707)

Science Applications, Inc., undertook this project to determine whether fault tree methodology could be used to predict the reliability of a fossil fuel power plant. As a test case, a fault tree model was developed and evaluated for an existing gas turbine power plant. The overall plant reliability prediction for producing steam for 500 consecutive hours was 0.965. This value was considered reasonable by utility personnel, and it was concluded that the fault tree technique is a useful tool for this kind of reliability prediction. *EPRI Project Manager: Jerome Weiss*

Workshop Proceedings: Safety and Environmental Aspects of Deuterium-Tritium Fusion Power Plants
ER-821-WS (WS-77-43)

In September 1977, Battelle, Pacific Northwest Laboratories held a workshop on safety and environmental aspects of fusion power plants. The objective was to promote incorporation of safety and environmental protection features into reactor design, thereby reducing the expense and delay of backfitting safety systems after designs are complete. *EPRI Project Manager: Noel Amherd*

NUCLEAR POWER

Study of Magnetic Filtration Applications to the Primary and Secondary Systems of PWR Plants
NP-514 Final Report (TPS76-665)

A comprehensive state-of the-art review of magnetic filtration has been made by Westinghouse Electric Corp. with emphasis on application of the technology to nuclear power plant fluid systems. Conceptual designs for six potential applications are described and evaluated on the basis of their potential cost-effectiveness. Three systems configurations (one for primary coolant filtration and two for secondary coolant filtration) were selected as having high potential. Application to the primary coolant is predicted to reduce the plant radioactivity from deposited crud by at least a factor of 2. In the secondary side, a 75–85% reduction in sludge accumulation in the steam generators is possible, with the attendant reduction in the probability of steam generator corrosion problems. Specific test programs under realistic plant conditions for both primary and secondary applications are recommended. *EPRI Project Manager: Robert Shaw*

Multifluid Models for Transient Two-Phase Flow
NP-618-SR Special Report

This report by McMaster University describes the theory and research objectives involved in the development of advanced thermal-hydraulic models. The difficulties associated with both state-of-the-art models and advanced models are discussed in detail. *EPRI Project Manager: Lance Agee*

Pool-Type LMFBR Plant: 1000-MW (e) Phase A Design
NP-646 Final Report, Vols. 1–9 (RP620-20)

This report describes the work performed in a team effort by General Electric Co. and Bechtel Corp. during the EPRI-sponsored Phase A design project for a 1000-MW (e) pool-type LMFBR. It describes the overall plant, structures, and systems of a pool-type LMFBR, with emphasis on major design features that are of special concern and are unique to the pool concept.

During Phase A, General Electric established the nuclear steam supply system (NSSS) basic characteristics and design bases, analyzed design alternatives, developed the overall NSSS conceptual design, and defined specific design approaches for NSSS components and subsystems. Bechtel performed the NSSS ex-pool piping arrangement and mechanical design and designed the balance of plant (BOP) to coordinate with the NSSS. The integrated plant design provided the bases for Bechtel to develop necessary plant seismic data used in design of the NSSS. It also provided the bases for indicating trends in BOP cost differentials between the Phase A pool plant and the equivalent loop plant. *EPRI Project Manager: James Duffy*

Spatial Distribution of Fission-Product Gamma-Ray Energy Deposition in LWR Fuel Elements
NP-672 Final Report (RP492-2)

EPRI sponsored research into spatial deposition of gamma-ray energy in the core of nuclear reactors following shutdown. This work by the University of Virginia was intended to provide a benchmarked tool for use in safety analyses of postulated LOCAs. Present NRC regulations state that certain important safety margins must be demonstrated for the unlikely event of a LOCA. Variables of interest include peak cladding temperature of the fuel and the amount of H_2 produced by radiolysis in the coolant. The peak cladding temperature problem is of concern in the short time frame (i.e., 0–10^3 s) immediately following reactor shutdown in a LOCA analysis, while for H_2 radiolysis, the time frame of interest is in terms of days or weeks. *EPRI Project Manager: Frank Rahn*

Effects of Hydrogen Peroxide Additions on Shutdown Chemistry Transients at PWRs
NP-692 Final Report (RP821-1)

Hydrogen peroxide injection has been employed on initial cooldown prior to refueling outages at numerous PWRs. The injection increases primary coolant cobalt-58 levels during a period when purification can be used to remove the released activity without affecting the refueling schedule. To quantify the effects of the peroxide injection, test programs were performed by Nuclear Water & Waste Technology, Inc., at Turkey Point-3, where peroxide was employed, and at Kewaunee, where no addition was made. Results of these programs and of a limited survey of other utility studies are discussed. *EPRI Project Manager: Robert Shaw*

Wind Field and Trajectory Models for Tornado-Propelled Objects
NP-748 Final Report (RP308)

California Institute of Technology undertook to provide a method of realistically predicting the trajectories of tornado-generated missiles. This report contains the results of the second phase of the project, which uses the "worst case" tornado defined in the initial phase, a theoretically consistent wind model, measured aerodynamic coefficients, and a six-degree-of-freedom trajectory code to compute maximum credible tornado missile speeds.

Of special importance are the results for postulated 30-cm-diam (12-in-diam) pipe and automobile missiles, which currently have the most influence on nuclear plant design. Because the aerodynamic coefficients for these missiles are based on data from full-scale wind tunnel tests, the maximum speeds for these missiles presented in this report merit a high degree of confidence. In addition, three-degree-of-freedom coefficients were developed for use in simplified methods. *EPRI Project Manager: George Sliter*

Comprehensive Study of the Operating and Testing Experience During the Startup and Initial Operation at the Fort St. Vrain HTGR
NP-760 Key Phase Report (RP457-1)

This report by The S. M. Stoller Corp. documents the important experiences gained at the Fort St. Vrain plant during initial startup and operation at power levels up to 29% of rated levels (April 1975–July 1977). This is the last of three phases; the previous phase reports covered preoperational testing and low-power startup testing. *EPRI Project Manager: James Kendall*

Evaluation of Ultrasonic Techniques for Detection of Stress Corrosion Cracks in Stainless Steel Piping
NP-761 Final Report (RP449-1)

Argonne National Laboratory evaluated ultrasonic pulse-echo techniques for detecting intergranular stress corrosion cracking in 102-, 252-, and 660-mm type-304 stainless steel piping. Transducers with varying frequency, size, and beam angle were used and compared for effectiveness. Focused, nonfocused, and single- and dual-angle-beam transducers were also tested. In addition, curved and flat transducer wedges were compared. Artificial reflectors of varying size and orientation were employed in both welded and unwelded pipes to establish flaw-detection reliability and sensitivity.

Data from welded pipe sections with laboratory-grown and field-induced intergranular cracks are presented. Some statistical data for establishing the probability of detection of small reflectors are presented for artificial reflectors in 102-mm pipes and small stress-corrosion cracks in 254-mm pipes. Problems associated with spurious ultrasonic signals resulting from weld geometry are discussed. *EPRI Project Manager: Richard Smith*

Portability Studies of Modular Data Base Managers
NP-762 Interim Report (RP694 and RP814)

Within the nuclear electric power industry today, there are several different combinations of computing hardware and operating-system software. The movement and maintenance of computer programs and data bases are often difficult and time-consuming because of the basic differences between computing hardware and system software and because of the frequent changes made in the hardware and software to increase computing-machinery efficiency. To eliminate some of these difficulties, two capabilities are necessary: the ability to efficiently link and execute computer programs written at various installations and the ability to store, retrieve, and transmit large amounts of data.

This report describes efforts made to determine the "portability" of the DATATRAN 2 and JOSHUA systems. The first part (on DATATRAN portability) was prepared by Rensselaer Polytechnic Institute. The second part (on JOSHUA portability) was contributed by Intermountain Technologies Inc. *EPRI Project Managers: Lance Agee and Robert Whitesel*

GO Methodology

NP-765, NP-766, NP-767 Final Reports (RP818)

GO methodology is a computerized technique for system reliability analysis. The methodology consists of two parts—system reliability evaluation and system fault sequence identification. The method employs a straightforward inductive logic for constructing system models; all possible system response modes, both successes and failures, can then be determined.

The work on the GO methodology is presented in three reports by Kaman Sciences Corp. The first report (NP-765), a brief overview of the GO methodology, gives simple examples to demonstrate the GO method concept. A list of engineering applications is also provided to show the versatility of the methodology. The two companion reports discuss detailed technical and application aspects of the GO reliability evaluation (NP-766) and the fault-finder procedures (NP-767). *EPRI Project Manager: Boyer Chu*

Tornado Missile Risk Analysis

NP-768 and NP-769 Final Report (RP616)

Carolina Power & Light Co. has developed mathematical models of the events contributing to the tornado missile hazard at nuclear power plants. These models, which consider the major sources of uncertainty in a probabilistic framework, have been structured into a sequential event formalism, which permits the treatment of both single and multiple missile generation events. A simulation computer code using these models has been developed to obtain estimates of tornado missile event likelihoods. Two case studies have been analyzed: a single-unit (nuclear steam supply system) study using the current NRC set of missile types and a two-unit study using an expanded set of missile types. Preliminary results suggest that the likelihood of missile strike and that of subsequent plant damage may be acceptably small. *EPRI Project Manager: Boyer Chu*

Uprated DC Power System and Thermal-Hydraulic Facilities at Columbia University

NP-773 Final Report (RP345-1)

The necessity of carrying out large-scale nuclear thermal-hydraulic simulations is increasing. Such experiments call for large power sources, and to meet those requirements, the dc power system at the Heat Transfer Research Facility of Columbia University has been upgraded to 11.5 MW. The uprated system, its installations, various subsystems, and operations are described. Also described are the thermal-hydraulic loops and their auxiliary systems. *EPRI Project Manager: Kjell Nilsson*

Performance Measurement System for Training Simulators

NP-783 Interim Report (RP769-1)

In the first project phase, General Physics Corp. designed, installed, and tested (on the training simulator at Browns Ferry nuclear power plant) a performance measurement system capable of automatically recording statistical information on operator actions and plant response. Key plant variables and operator actions were monitored and analyzed by the simulator computer for a selected set of four operating and casualty drills. *EPRI Project Manager: Randall Pack*

Air-Water Countercurrent Annular Flow in Vertical Tubes

NP-786 Interim Report (RP443-2)

Air-water countercurrent flow characteristics in 2.5-cm and 5.1-cm vertical tubes were investigated by Dartmouth College. Experimental measurements included flow rates for air and water, pressure losses, pressure gradients, and liquid fractions. Tube-end geometries were altered to study their influence on flow characteristics. Liquid-fraction measurements indicated that the countercurrent flow may be divided into three regions based on the relative magnitudes of interfacial and wall shear stresses. The dependence of interfacial friction factor on the liquid fraction was isolated. The mechanism that limits countercurrent flows within a tube was modeled by a simple theory. Salient features of the theory were demonstrated. Comparisons between the theory and some experimental data are presented in the report. *EPRI Project Manager: K. H. Sun*

Water Impact Tests of Rigid and Flexible Cylinders

NP-798 Final Report (RP817)

Developmental Sciences, Inc., conducted tests of both rigid (thick-wall) and flexible (thin-wall) cylinders of two sizes to study the response of structures to water impact. The cylinders were driven vertically downward into a tank of water to provide a first-order simulation of possible pool-swell impact of BWR pressure suppression system components following a hypothetical LOCA. The models were instrumented to measure pressure, strain, acceleration, and force.

Although the models were simplified versions of their counterparts in a BWR (and hence cannot be used to accurately predict the behavior of the more complex prototype), the tests provided extensive data that can be used to validate developing analytic techniques for calculating the complex phenomenon of hydrodynamically impacted structures.

Comparisons of data for rigid and flexible cylinders showed that flexibility reduces local impact pressures but does not reduce the peak impact force (pressure integrated over the cylinder diameter). Also, agreement of data from the two model sizes supported the applicability of scaling laws to both elastic and inelastic behavior of structures under the water impact conditions examined in the test program. *EPRI Project Manager: George Sliter*

Comparison of Experimental Results With Analytic Predictions for LOFT Nonnuclear Tests With Core Simulator

NP-800 Final Report (RP496-1)

This report by Intermountain Technologies Inc. presents the results of a comparison between analytic predictions and actual test results for four nonnuclear LOFT tests. The test predictions were made with the RELAP thermal-hydraulic computer code. The LOFT tests included L1-1, L1-2, L1-3A, and L1-4, all of which were nonnuclear blowdown tests conducted with a core simulator in the reactor vessel.

The validity and usefulness (for comparison with analysis) of the experimental results as reported by EG&G Idaho, Inc., are also reviewed. *EPRI Project Manager: Lance Agee*

WAMCUT, A Computer Code for Fault Tree Evaluation

NP-803 Final Report (RP767-1)

WAMCUT is a code in the WAM family that produces the minimum cut sets (MCS) for a given fault tree. The MCS are useful, as they provide both a qualitative evaluation of a system and a means of determining the probability function for the top of the tree. The program, which was developed by Science Applications, Inc., is efficient and will produce all the MCS in a very short computer time span. *EPRI Project Manager: Gerald Lellouche*

Technology Assessment of the Gas Turbine–High-Temperature Gas-Cooled (Helium) Reactor

NP-805 Interim Report (RP900)

In late 1976, EPRI initiated a series of technology assessments to aid in government and industry evaluations of the commercialization potential of high-temperature gas-cooled (helium) converter and breeder reactors. Previous reports and surveys covered the steam-cycle and breeder projects as developed in the United States by General Atomic Co. This final report by NUS Corp. examines the (closed-cycle) gas turbine—high-temperature gas-cooled reactor. The report emphasizes the configuration of the system, the technology background of the major components, and the relatively new design areas of heat source and power conversion system integration, which will be required for any system introduced. *EPRI Project Manager: Melvin Lapides*

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September 1978