The Breeder: When and Why

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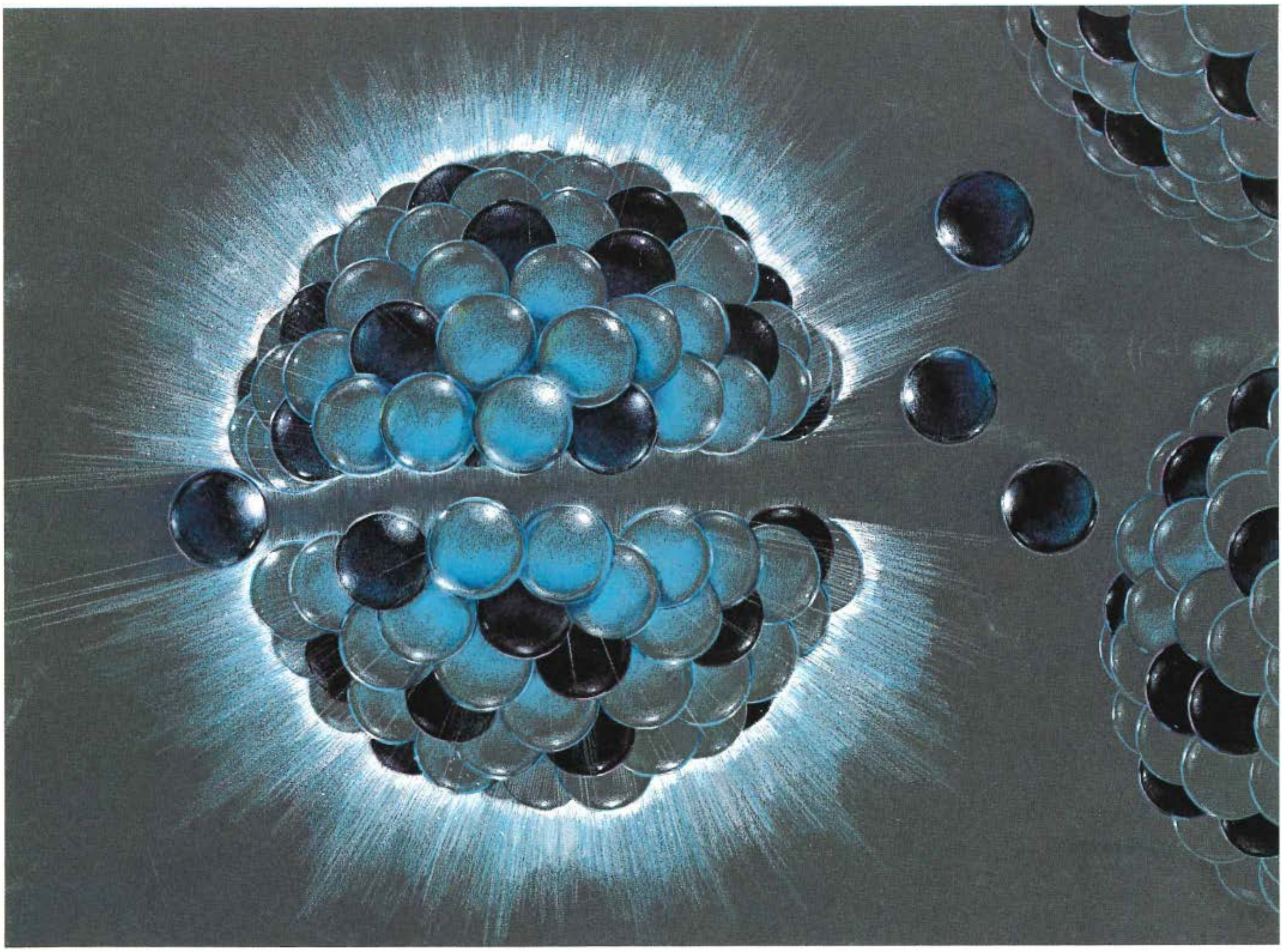

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Address correspondence to:
Editor, EPRI JOURNAL
Electric Power Research Institute
3412 Hillview Avenue
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Cover: The instant of atomic fission—the impact of a single neutron yields heat energy as well as additional neutrons to continue a chain reaction.

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A Cooperative Push for the Breeder

The electric utility industry shares with government the goal of providing adequate supplies of power at acceptable environmental and economic costs.

Traditionally, however, each sector looks at its contribution with a different time perspective. Government is rightfully concerned with long-range energy needs, with economic development, with energy supply and demand, and with national security. The electric utility industry has a primary interest in meeting immediate energy needs: maintaining its responsibilities to customers by keeping cities lighted, homes heated, and the wheels of industry turning.

One of the few demonstrated technologies that can bridge these two orientations is the liquid metal fast breeder reactor (LMFBR). But, as is the case with a number of other technologies in an advanced stage of development, it is not yet commercially viable.

The feature article, "The Breeder: When and Why," which begins on page 6 of this issue, describes a joint venture of the government (through ERDA) and the electric utility industry (through EPRI) to bring the LMFBR into the realm of practical application. The contributions of science and technology are valuable to society only when they become practical and economic, and we believe that this joint project holds excellent promise of accelerating the availability of the LMFBR.

Milton Levenson, Director
Nuclear Power Division

Authors and Articles

Two articles this month are especially timely: our state-of-the-art feature on the new LMFBR design projects and an article on the joint EPRI–EEI study on electric utility rate design.

Although both subjects have long been familiar to the utility industry, neither arrived on the scene as a defined mission for EPRI until last year. Both command high interest because of their potential contribution to national precedent, if not to specific federal policy. Budget figures and time limits further reflect their importance: $30 million and 30 months for the LMFBR projects; $1 million and 12 months for the rate design study.

▫ Virtually an entire generation of engineers have devoted their careers to nuclear power, among them EPRI's Lawrence E. Minnick and GE's Mike Murphy. In writing the cover story, "The Breeder: When and Why" (page 6), they each drew on more than 20 years of nuclear engineering experience.

Minnick earned his degree in mechanical engineering from Worcester Polytechnic Institute in 1948 and then joined the New England Electric System. Breeder reactor technology became a focus of his work in 1954, when he took a 3-year leave of absence to work for Atomic Power Development Associates on fuel design, development, and testing for the Fermi fast breeder.

Minnick then joined Yankee Atomic Electric Co. and held successive responsibilities in R&D and engineering for nuclear plants at Rowe, Massachusetts, East Haddan, Connecticut, Wiscasset, Maine, and Vernon, Vermont. In 1968 he was named engineering vice president of Yankee Atomic Electric and assumed full technical charge of all 4 Yankee projects.

Minnick today wears two hats, one (since 1974) as director of the Engineering and Operations Department in EPRI's Nuclear Power Division, the other as comanager of ERDA–EPRI's shared LMFBR design projects.

Mike Murphy also studied at Worcester Polytechnic Institute and earned an MS degree in electrical engineering in 1940. Then, after 5 years with the navy, he began a 30-year career with General Electric, from which he is now on loan to EPRI.

Murphy was at Richland, Washington, for 5 years, working on the design of plutonium production reactors and reprocessing facilities. For the last 20 years he has worked on LMFBR development, most recently as GE's advanced engineering manager at Sunnyvale, California.

▫ Authorship is no new thing to Robert G. Uhler, who asks, "Should Utility Rates Be Redesigned?" (page 12). He ran the campus humor magazine at Ohio University while earning degrees in both commerce and languages in 1959. In 1973, with Dr. Rendig Fels, he produced *Economic Problems and Policies,* a casebook since adopted by more than 100 colleges and universities.

In between, Uhler took an MA in economics at Ohio State and a regular army commission, eventually teaching economics for 3 years at West Point.

Uhler's later teaching and graduate work in economics at Vanderbilt University led him to the Federal Power Commission in 1972. As chief of economic studies in the Office of Economics, he testified in a dozen cases on behalf of the FPC, the AEC, and the NRC.

Fascinated by public policy issues that have broad consequences for utility management and the general public, Uhler accepted the opportunity to join EPRI last year as executive director of the Electric Utility Rate Design Study.

▫ The technical feature in this issue is "Solid Dielectrics for High-Voltage Transmission Cables" (page 18). It is also timely, but reflects the more measured scale of investigation and evaluation familiar to its author, Felipe Garcia.

Following his 1960 graduation in electrical engineering from Carnegie Institute of Technology, Garcia went to work for General Cable Corp. During 10 years there and 4 years with Phelps Dodge Cable & Wire Corp., he was involved in the development of ac and dc transmission cables and their accessories, as well as of cable manufacturing methods. Later, as assistant R&D director for Phelps Dodge, he helped select and implement many cable research projects.

Garcia has been doing similar work since joining EPRI in 1975 as a project manager in the Transmission and Distribution Division, where he is responsible for 6 projects and involved in 14 others. Despite his management of research in laminar and extruded dielectric cable systems, Garcia occasionally misses the days when he was doing his own lab measurements.

Minnick

Murphy

Uhler

Garcia

The Breeder: When and Why

Lawrence Minnick and Mike Murphy

Construction of a prototype liquid metal fast breeder power plant should begin by the end of 1980. Operational LMFBRs in the following years will relieve pressure on United States uranium and coal reserves.

With the award of contracts in December to three reactor vendors and three architect-engineers, the ERDA–EPRI liquid metal fast breeder reactor (LMFBR) design projects began a key step toward making the LMFBR available for large-scale electric power generation.

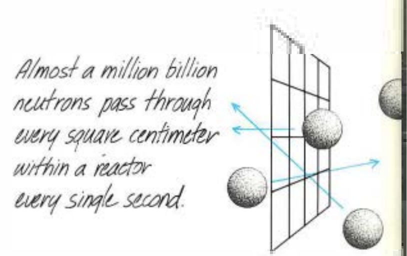
The effort was organized early in 1975 as a joint endeavor of ERDA and the electric utility industry, represented by EPRI. At the conclusion of the design phase in mid-1978, a choice of breeder designs should be available and construction of at least one prototype should follow.

The fast breeder system is essential if we are to retain the option of using nuclear energy for electric power generation after our low-cost uranium reserves have been exhausted. We are experiencing the trauma of reduced supplies of petroleum and natural gas as fuels for electric generating plants, and in a matter of decades we will be left with coal and uranium.

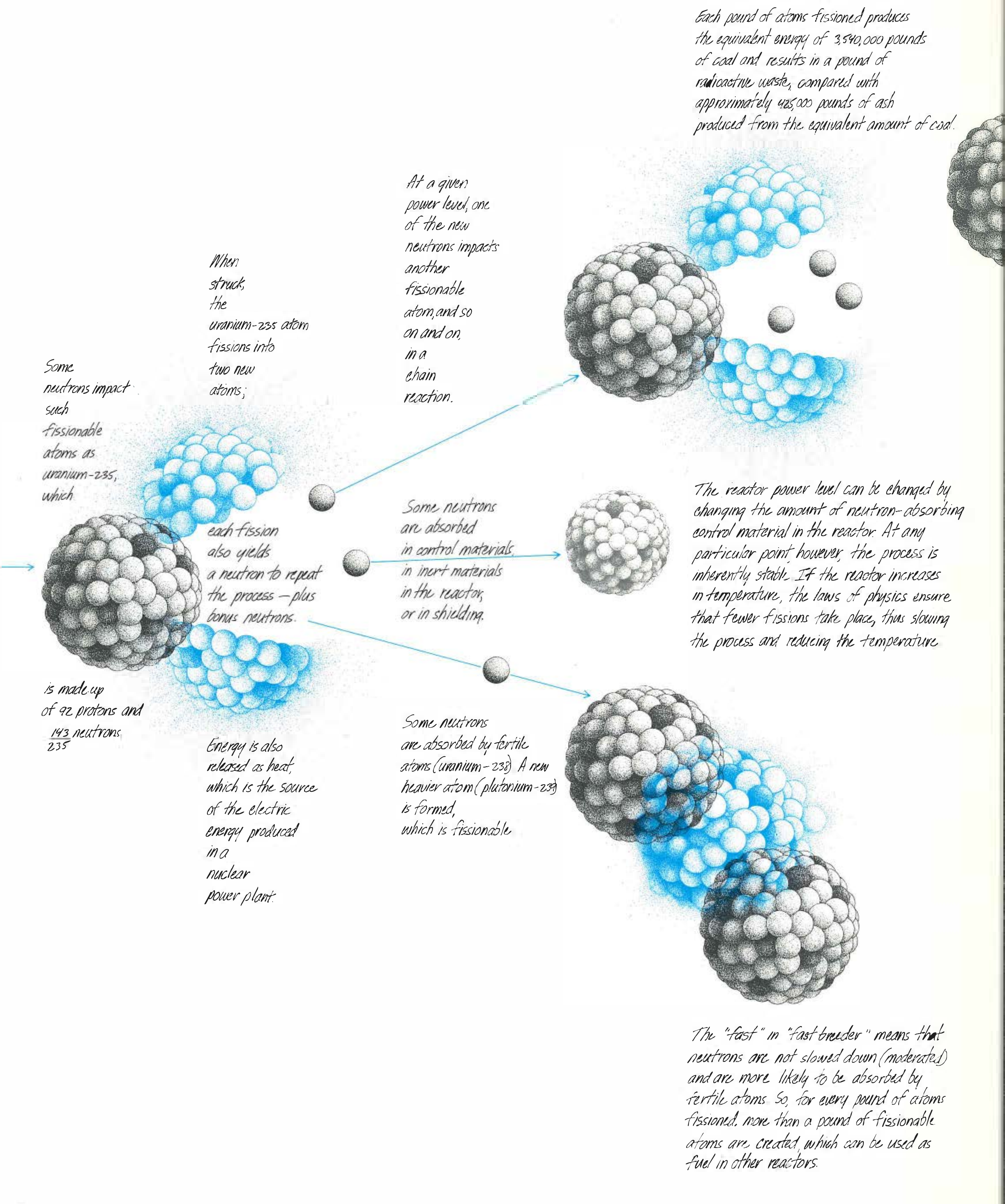
It is vital that we not delay breeder development, or we run the risk of a uranium shortage that could diminish the nuclear option and leave us chiefly dependent on coal for electric power growth before the end of this century.

The situation became highly visible in the past decade: oil consumption for the first time exceeded domestic production, domestic natural gas production began to peak out, and the oil-producing countries organized to establish and control prices. In 1973 the Arab oil producers embargoed oil shipments to the U.S., demonstrating how vulnerable our economy had become in its reliance on imported fuels, particularly the fluid fuels that are vital to our transportation needs.

This emphasized and dramatized the fact that the U.S. could rely on only two fuel choices for new electric generating plants for the rest of this century—coal and uranium. New hydroelectric and geothermal units can make only small contributions when measured against the expected need.



Lawrence Minnick is comanager of the ERDA–EPRI LMFBR design projects and also director of the Engineering and Operations Department, Nuclear Power Division, EPRI. Mike Murphy, on loan to EPRI from General Electric Co., is a member of the technical support staff for the ERDA–EPRI LMFBR design projects.


Some neutrons impact such fissionable atoms as uranium-235, which
is made up of 92 protons and 143 neutrons.
143/235
When struck, the uranium-235 atom fissions into two new atoms;
each fission also yields a neutron to repeat the process — plus bonus neutrons.
Energy is also released as heat, which is the source of the electric energy produced in a nuclear power plant.
At a given power level, one of the new neutrons impacts another fissionable atom, and so on and on, in a chain reaction.
Some neutrons are absorbed in control materials, in inert materials in the reactor, or in shielding.
Some neutrons are absorbed by fertile atoms (uranium-238). A new heavier atom (plutonium-239) is formed, which is fissionable.
Each pound of atoms fissioned produces the equivalent energy of 3,540,000 pounds of coal and results in a pound of radioactive waste, compared with approximately 425,000 pounds of ash produced from the equivalent amount of coal.
The reactor power level can be changed by changing the amount of neutron-absorbing control material in the reactor. At any particular point, however, the process is inherently stable. If the reactor increases in temperature, the laws of physics ensure that fewer fissions take place, thus slowing the process and reducing the temperature.
The "fast" in "fast breeder" means that neutrons are not slowed down (moderated) and are more likely to be absorbed by fertile atoms. So, for every pound of atoms fissioned, more than a pound of fissionable atoms are created, which can be used as fuel in other reactors.

Our challenge is clear: How do we supply our future energy needs, using domestic fuels to the greatest extent possible? An obvious response is that since uranium is a large fuel resource, we should lean heavily on it. Further, since nuclear energy can only be utilized when converted to electricity, it is probable that this will lead to greater reliance on electricity relative to other forms of energy.

What rate of growth?

Projections of electric power growth to the year 2000 vary widely. However, if we assume as a continuing national policy that we must meet the needs of a population growing in expectation as well as in size, then our energy supply plans must be based on the need to provide for the greatest economic growth that can reasonably be expected. On this basis, and for at least the rest of this century, we must anticipate that electric demand will continue to grow at a rate in the range of 5% to 7% per year, with a doubling time between 10 and 15 years. We should plan for new capacity to be both coal- and uranium-fueled, since it is quite unlikely that either could be expanded rapidly enough to carry the entire load or that any other generation system can make a significant difference before the end of the century.

If by the year 2000 half of the electric generating capacity utilizes coal and the other half uranium (using only light water reactors) and if we have a 10-year doubling time for electric consumption, then coal production will need to increase six times over present rates, and we will require uranium resources eight times greater than today's proven reserves. With the 15-year doubling time the resource requirements are about half. To the extent that we fail to expand production of either of these fuels, the deficiency will have to be made up by further increase in the other. The alternative is to put breeder reactors into commercial operation. A far less desirable course is to accept an electricity shortage by the end of the century.

LMFBR fuel requirements

The availability of breeders on a large scale will reduce the pressure to find, mine, and process new uranium. This follows from the basic differences between the fuel cycle of the light water reactor (LWR) and of the breeder reactor and the important ways in which they interact.

Uranium, as found in nature, is a mixture of two isotopes: 99.3% ^{238}U and 0.7% ^{235}U. ^{235}U is the only fissile isotope abundant in nature and for that reason is the primary fuel for LWRs. For this application, however, it is necessary to increase the concentration of ^{235}U in the $^{235}U/^{238}U$ mixture up to about 3%. During this "enrichment" process a large quantity of "depleted" uranium is produced as a by-product. For example, for every ton of LWR fuel (3% ^{235}U content), 5 tons of natural uranium must be mined and 4 tons of depleted uranium by-product (about 0.2% ^{235}U) are produced. In the production of fully enriched uranium for weapons or naval vessel propulsion, some 200 tons of depleted uranium are created for every ton of product. This depleted uranium, which is otherwise worthless, can be used as a fertile material for breeding in the LMFBR.

The country now has in storage more than 200,000 tons of depleted uranium resulting from the production of enriched uranium for all purposes. This is enough to supply the uranium feed requirements of the LMFBRs for at least a century. Though worthless in its present form, this material potentially contains energy equivalent to 400 million tons of coal worth many trillions of dollars.

The fuel cycles of the LWR and LMFBR interact in another important way. During normal operation of the LWR, the ^{238}U in the fuel captures neutrons and is transmuted into ^{239}Pu, a fissile isotope. Much of this plutonium is burned in place and accounts for almost half of the total energy produced by the LWR system. The unburned plutonium can be recovered from the discharged LWR fuel and used as the initial fissile load for an LMFBR.

The initial fuel load for a 1000-Mwe LMFBR would consist of some 4 tons of plutonium and about 36 tons of uranium obtained from the existing stockpile of depleted uranium. Once in service, the 1000-Mwe LMFBR will need between 1 and 2 tons of depleted uranium annually, in exchange for which it will produce a surplus of 0.3 tons of plutonium, which can be used to supply the starting inventory for new LMFBRs. Once an LMFBR has been put in service, its lifetime fuel supply is assured at a price that is essentially inflation-free.

Breeder history

The discovery of the fission of ^{235}U and the concept of the chain reaction involving sequential fissioning of ^{235}U atoms soon led to the concept of breeding by the introduction of ^{238}U into the chain reaction to create additional fissile material. Design and development of an experimental breeder reactor (EBR) began in 1946 at the Argonne National Laboratory. EBR-I was completed in 1951 at the National Reactor Testing Station at Idaho Falls and generated the world's first "nuclear electricity"—200 kwe—in 1951. EBR-I was followed in 1965 by EBR-II, a 20,000-kwe unit now in its twelfth year of active service, generating electricity and providing valuable experience and experimental facilities in support of the U.S. LMFBR development program.

The decision to develop the LMFBR has been reached independently by every nation that has "gone nuclear," with the exception of Canada. Figure 1 shows the relative timing of the major breeder programs worldwide. Overseas, breeder development work started in the United Kingdom, France, and Russia in the mid-1950s and in Germany and Japan a decade later.

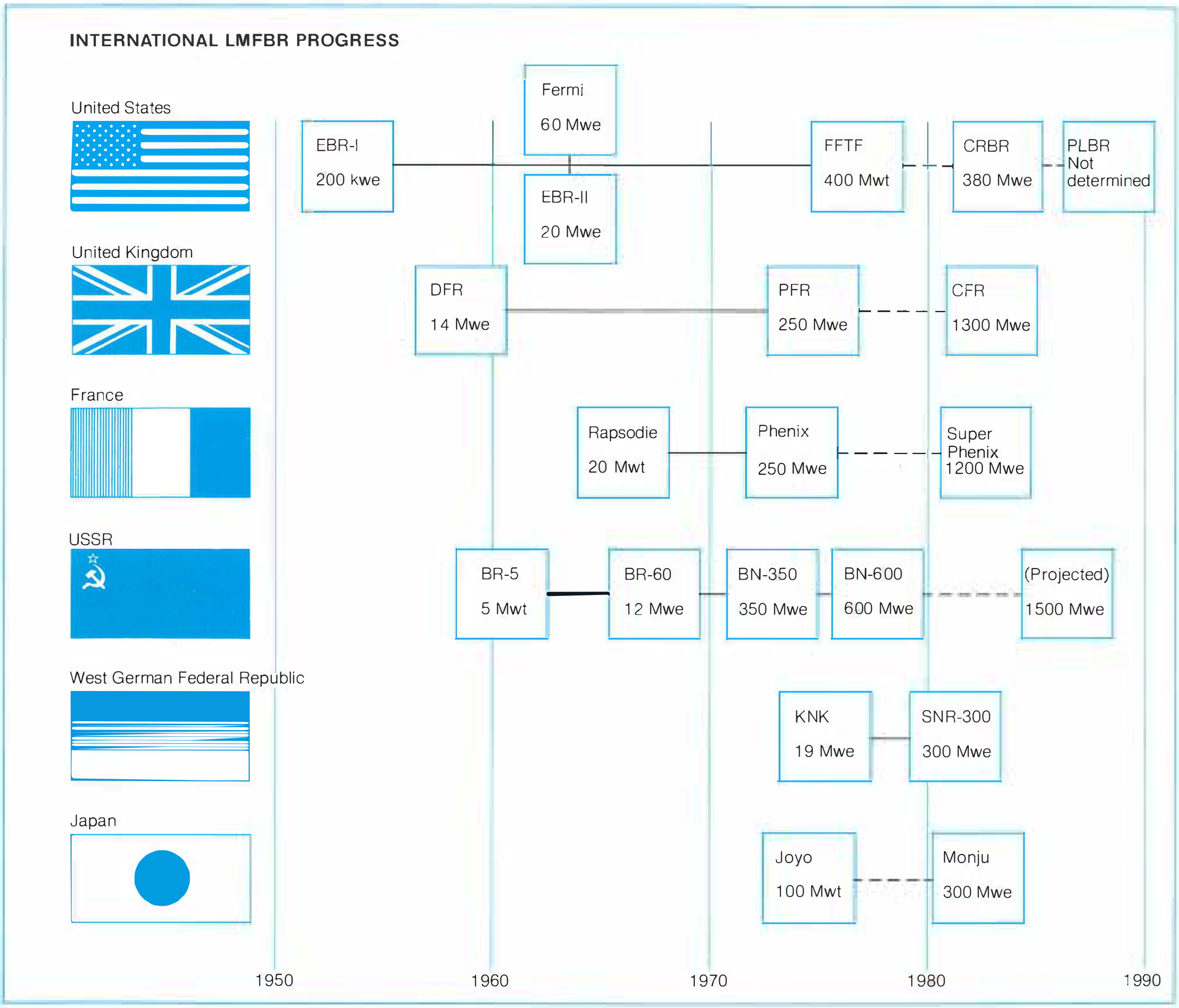
The French program has been the most successful LMFBR program to date. The 250-Mwe Phenix demonstration plant started full power operation in 1973 and has had excellent experience since; during its first year at full power its availability was greater than 80%. Construction of a near-commercial 1200-Mwe Super Phenix is scheduled to start this year.

The British 250-Mwe PFR was completed in 1974. Full power operation has been temporarily limited by steam generator problems. Start of construction of a 1300-Mwe commercial unit is scheduled for 1977.

The Soviet program has included the 350-Mwe BN-350, which has been operating since 1973. It, too, has experienced steam generator problems. The BN-600 is scheduled to go critical in 1976.

During the 1960s the U.S. program concentrated primarily on the development of the technology basic to fast reactors and sodium-cooling systems. Focus then shifted to the specific needs of the fast flux test facility (FFTF), a 400-Mwt reactor system designed to provide fast neutron flux irradiation facilities for testing advanced LMFBR fuel. The FFTF is now in construction with completion scheduled for 1978.

In 1972 design work was started on the 380-Mwe Clinch River breeder reactor (CRBR) demonstration plant to be constructed and operated on the TVA system. The CRBR will use many

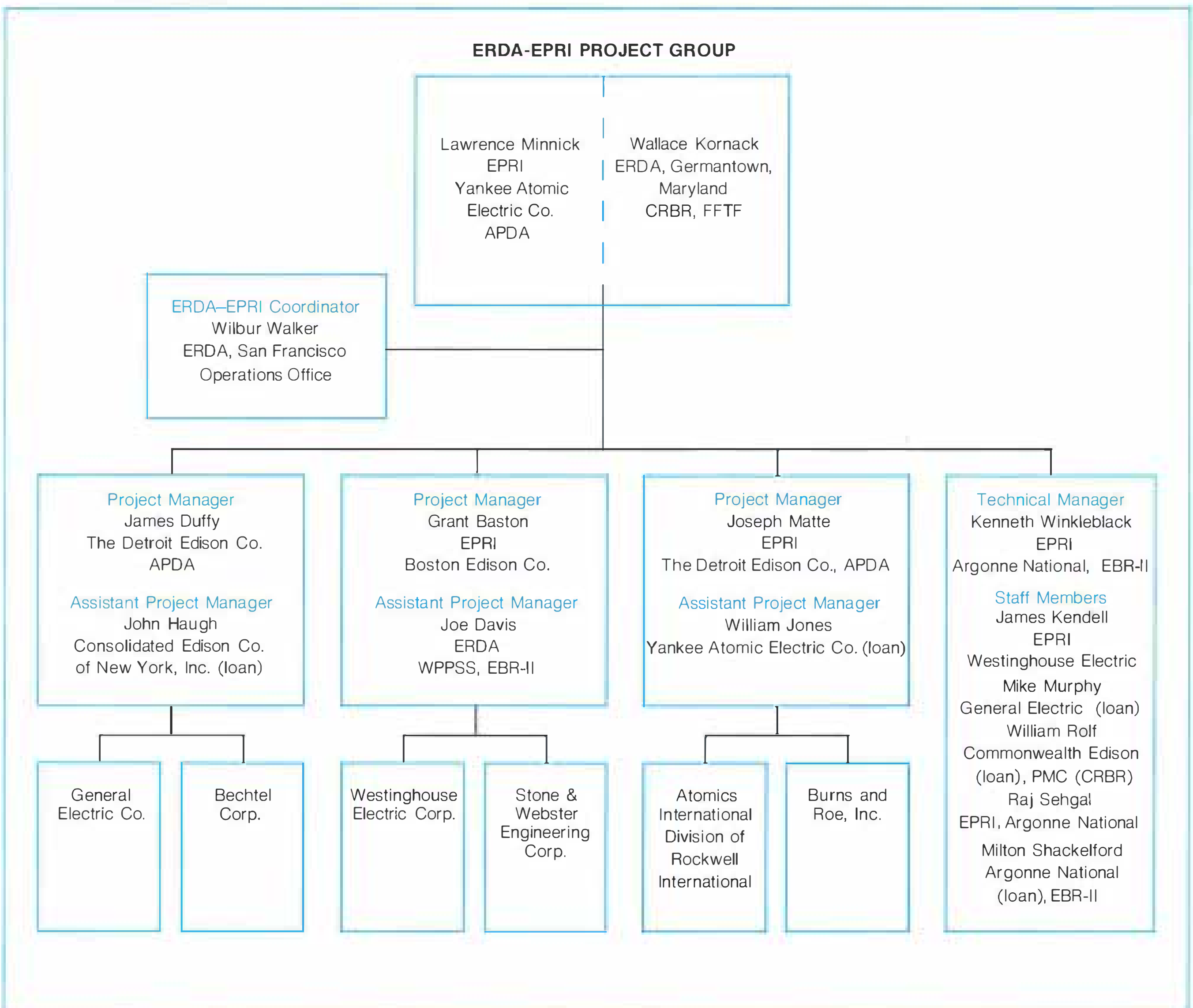


of the components and systems that were developed for the FFTF. It is being built by the government with technical and financial assistance from the electric utility industry. Its completion and operation will be a significant step toward making available a viable breeder option in the U.S.

ERDA–EPRI joint program

The next step toward availability of commercial breeder technology in the U.S. is the design of a prototype of a commercial LMFBR. Early in 1975 this effort began with the formation of a joint ERDA–EPRI group to solicit proposals from U.S. reactor manufacturers and architect- engineers for the design of a safe, maintainable, and licensable large breeder reactor power plant. Proposals were prepared and evaluated; six contractors were selected and formed into three reactor-manufacturer—architect-engineer teams; contracts were negotiated; and in mid-November of last year, design work was started.

The prototype large breeder reactor (PLBR) program is a jointly sponsored government-industry program with costs and management responsibility shared equally by ERDA and EPRI. As shown in Figure 2, the organization that will coordinate and manage the three separate design projects will combine the experience of the electric utilities, ERDA, EPRI, and the national laboratories. This background, together with that of the contractors, includes the project management, design, construction, licensing, and operation of



LWR power plants as well as of sodium-cooled reactors and all phases of fast reactor and sodium coolant technology, including that developed for FFTF and CRBR.

The work is scheduled to be completed in 30 months at a total cost of up to $30 million. At that time—mid-1978—there should be available a selection of breeder designs that will permit at least one prototype to be committed for construction.

From the outset ERDA and EPRI have agreed on several basic principles to be followed throughout the work.

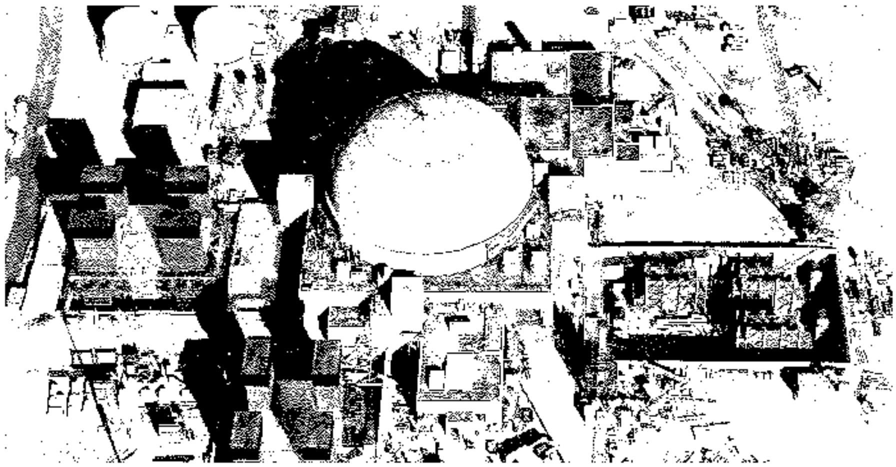
□ It is expected that a utility or group of utilities will wish to construct and operate one or more of the breeder designs developed. Thus, at the conclusion of the work, each reactor vendor will be requested to submit a commercial proposal to potential customers for providing an LMFBR nuclear steam supply system and the architect-engineers will be asked to submit proposals for their services in designing and constructing the plant.

□ The plant designs will be based to the largest possible degree on existing and demonstrated technology. This will allow plant construction at the earliest practicable date and will provide maximum assurance of plant reliability.

□ Utility industry operation, maintenance, and inspection requirements will be reflected in the plant designs. It will be EPRI's responsibility to see that this is accomplished.

□ Competition between the contractor teams will be maintained and encouraged in order to enhance the quality of the designs and help ensure the probability of a competitive industry for the future.

ERDA's fast flux test facility (FFTF) at Hanford, Washington, is the only LMFBR under construction in this country. The dome is the main containment and the two 4-towered structures are "heat dumps"—air-cooled sodium radiators that will dissipate heat from the 400-Mwt reactor during testing of advanced breeder reactor fuels.



Work plan

Phase I of the work, spanning 8 months, will establish two basic characteristics of the designs: plant capacity and operating temperature. It will also define a number of ground rules, such as site characteristics (including seismic and weather assumptions) and economic parameters to be used in evaluating alternative designs and construction and operating costs.

The remainder of Phase I will involve the analysis of alternative design choices in the many components, systems, and subsystems required. At the conclusion of this phase, the basic design decisions will have been made and the general features of the plant established.

Phase II will cover 12 months and will include the further development of the overall concept, with specific design approaches defined for individual components and subsystems. The objective of this phase is to produce a complete and integrated conceptual design of the plant.

Phase III (expected to take 14 months) will complete the evolution of an internally consistent plant design and safety analysis, including a cost estimate, a plant construction schedule, and a set of specifications for the plant and its components.

Continuing utility guidance

A committee of senior utility executives has been organized by EPRI to serve as the LMFBR Utility Committee, which has the following objectives.

□ Provide utility input to the projects as they develop.

□ Ensure that the criteria and design approaches incorporate the requirements and objectives of the utility industry.

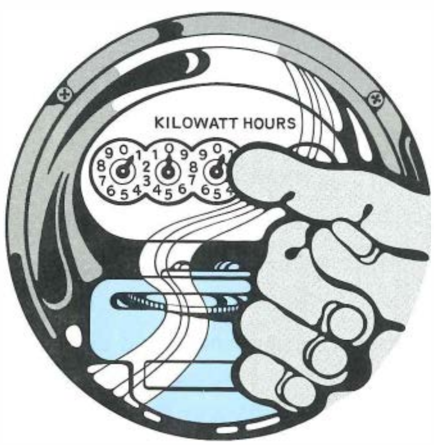
□ Advise on policy relationships between involved parties—ERDA–EPRI, vendors, architect-engineers, Nuclear Regulatory Commission, and utilities.

□ Consider the longer-term implications of LMFBR developments and evaluate the needs for further action.

□ Assist in conveying to the utility industry the results of the program.

Together with ERDA's ongoing development of basic technology and the cooperative ERDA–utility construction of the Clinch River breeder reactor, this ERDA–EPRI program will make possible the utilization of breeder technology at the earliest possible date.

The consumer pressures exist, the equipment is being developed, and the costing methods are being studied for setting rates in localized applications. An intensive EPRI–EEI program is assessing conceptual and technological problems of peak load pricing and load management for different regions of the United States. ▫ An EPRI program article



Should Utility Rates Be Redesigned?

Robert G. Uhler

Quite recently consumers discovered that PUC means Public Utility Commission. Further, they now realize that commission decisions affect their electric bills, now totaling some $50 billion annually after large rate increases in 1974 and 1975.

Commission decisions and practices have become front-page news. Regulators, at times unhappily, must now explain bewildering technical terms, such as *normalization,* to consumers and local newspapers.

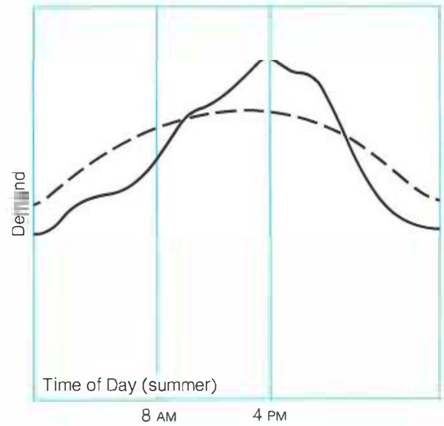
Utility executives are equally on center stage. One charismatic utility president has equipped his office as a ministudio so he can forcefully defend his company's rate filings on the six o'clock news.

Today's heightened public awareness and lively dialogue are salutary for a giant industry just entering its second century. Considering the rapidly evolving economic and political realities, this airing of costing concepts and ratemaking principles, as well as the evaluation of new technology for load management, seems both necessary and prudent. Thus, the country's largest industry is candidly reexamining the way it prices its output.

Defining the problem

As an integral part of rate design reappraisal, the National Association of Regulatory Utility Commissioners (NARUC) responded to increasing demands on the regulatory community to assess time-of-day pricing. At its 1974 annual meeting in San Diego, NARUC asked EPRI and the Edison Electric Institute (EEI) to examine the technology

Robert G. Uhler is executive director of the Electric Utility Rate Design Study, jointly sponsored by EPRI and EEI on behalf of NARUC.



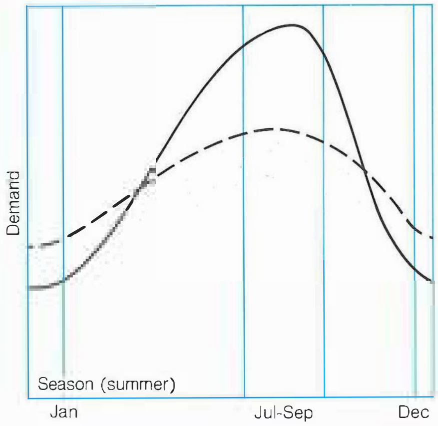
and cost of time-of-day metering and of electronic methods to control peak period usage of electricity. NARUC also asked EPRI and EEI to study the feasibility and cost of shifting various specific types of usage from peak to off-peak periods.

Conceptually, time-differentiated rates are not new ideas. They have been used in other industries for years. "Night owl" air travel, for example, is available at reduced fares. Similarly, long-run incremental cost is an echo of marginal cost-pricing concepts championed by economists for at least a hundred years. Moreover, for some time the electric utility industry has offered time-of-use rates (e.g., Georgia Power Co.'s summer-winter differentials and United Illuminating Co.'s day-night rates for customers with electric water heating).

Even before the consumer protests of the mid-1970s, time-differentiated and inverted rates had been advocated by environmentalists (*1*). These reformers were particularly critical of the declining block rates used throughout the electric utility industry. Then, as now, economic theorists provided the conceptual basis for alternative rate designs while ecologists garnered political support for such ideas as peak load pricing and marginal or incremental costing. In recent years, consumer reaction to inflation and recession has added a new wrinkle: low-usage, fixed, "lifeline" rates.

New trends

From the utilities' perspective, the attractiveness of doubling sales and capacity each decade lost its luster in the face of the Arab oil embargo and the financial setbacks caused by chronic inflation and the worst recession in more than three decades. Because electric utilities are both capital-intensive and regulated, growth in peak demand became a questionable variable in some investors' calculations. As market-to-book ratios tumbled, outside financing to build new plants became increasingly difficult, if not prohibitively expensive (*2*).



Simultaneously, consumers responded to the energy crisis in 1974 with conservation measures, and when industrial production nose-dived a year later, industrial electricity sales were hit hard. Kilowatt-hour sales flattened or declined and peak demand growth faltered, reversing an industry trend of decades.

Utility managers, in turn, cut back on construction programs, filed for rate relief in unprecedented amounts, and tightened operating expenses, especially in maintenance. Of particular relevance, they also funded rate design studies, stepped up load research, and sharpened forecasting tools.

Focus on peak load cost

NARUC was active well before its 1974 study request. Earlier that year, NARUC's executive committee had asked for a comprehensive staff report on electric utilities. The report is instructive because it cautiously summarized a shortcoming of present utility rate design:

> A major fault with current rate structures is that they ignore peak load costs. Since electricity is priced on the basis of its average cost per kilowatt hour of use by each customer class, peak loads are almost certainly underpriced. We recommend that consideration be given to peak load pricing as a way to relieve some of the financial and operating stress on the system and to assure that the incidence of costs falls on the appropriate user. However, we recognize that a substantial amount of work remains to be done before we can state with certainty that peak load pricing is desirable (*3*).

This cautious questioning of rate design is mirrored in the joint EPRI–EEI research *Plan of Study.*

Analyzing approaches to pricing

A brief summary of a few of the topics being considered underscores the balance between conceptual optimism and practical reservations. Topic 1, for example, includes an examination of fully allocated historic cost pricing and of long-run incremental cost pricing. Moreover, the effectiveness of summer-winter differentials, for example, and their relationship to traditional rate-making and peak load pricing are considered in this review. Work under Topic 1 includes development of cost-based rates for various defined periods (such as on-peak). These rates will be adjusted to a practical set of proposals compatible with metering capabilities and such regulatory standards as the revenue constraint, that is, the need for revenues to meet but not exceed a utility's legitimate costs.

Topic 1 is a rather ambitious review and appraisal of both theory and practice, but it is decidedly hedged. In this regard, one public utility regulator noted, "Although an economist must take some satisfaction from the current vogue of incremental cost and peak responsibility pricing, I confess to a growing sense of alarm over the expectations that its rapidly growing hordes of advocates seem to have about its consequences" (4).

EXACTLY WHAT IS UNDER STUDY?

These 10 topics define the scope of research now being done by a combination of task forces and consultants drawn from throughout the utility and regulatory fields. Complete descriptions of these efforts are set forth in the *Electric Utility Rate Design Study: Plan of Study*, September 24, 1975.

1. Analysis of Various Pricing Approaches: assess traditional theory and practice, as well as such innovative designs as peak load pricing
2. Elasticity of Demand for Electricity: assess price elasticity, both on average and at peak
3. Rate Experiments for Smaller Customers: evaluate present and possible rate experiments
4. Costing for Peak Load Pricing: develop costing methodology for peak load pricing, including incremental costing
5. Ratemaking: design peak-load-pricing rate forms consistent with revenue constraints and metering technology
6. Measuring Advantages of Peak Load Pricing: develop methodology for evaluating advantages of load shifting
7. Metering: assess existing equipment, including electronics
8. Technology for Utilization: assess equipment now available and useful for peak load pricing
9. Mechanical Controls: evaluate controls on customers' premises
10. Customer Acceptance: assess customer reaction to peak load pricing and load management

Designing peak load rates

Topic 5, on ratemaking, raises several important issues. For example, the *Plan of Study* acknowledges that the "translation of costs into rates is not a simple process, even assuming adequate measurement technology were available." Further, it explicitly addresses the complications of a revenue constraint if marginal costs are to be the basis for deriving prices. Finally, it contemplates an examination of the conceptual merits and applicability of the inverse elasticity rule, which is a theoretical basis for adjusting revenues to fall within the revenue constraint.

Also under Topic 5, the practical problems of metering small commercial and residential consumers are being explored. Recognizing that the concept of time-of-day rates may not be cost-justified for small customers on particular systems, the project examines "the problem of how to proceed with peak load pricing without adding significantly to current metering costs."

A basic premise of the study is that "the need for load management, its feasibility and its value, *depend on the nature of the peaking conditions being faced*" (emphasis added). The trick, obviously, is to incur modest costs and reap significant benefits.

Measuring advantages and costs

Topic 6 is an attempt to develop "a methodology by which *individual* utility systems can determine the quantity of electric usage that must be shifted to provide a substantial benefit from time-of-day pricing." This research effort is so crucial to resolving the NARUC-utility dilemma that three separate contracts will be awarded on this topic alone. The emphasis on individual utility systems underlines the fact that for certain companies an elaborate metering scheme with finely honed rate schedules may not be worth the effort. Conversely—and optimistically—there may be rich lodes that should be tapped.

Peak load pricing, even if widely adopted, would certainly not roll back average electric bills to preembargo levels. The rate of increase in the level of electric prices, however, might be slowed. To specific users, the greatest concern is the impact of time-of-use pricing on their bills. This would depend, of course, on each customer's original consumption pattern and his ability to change that pattern.

Facing uncertainties

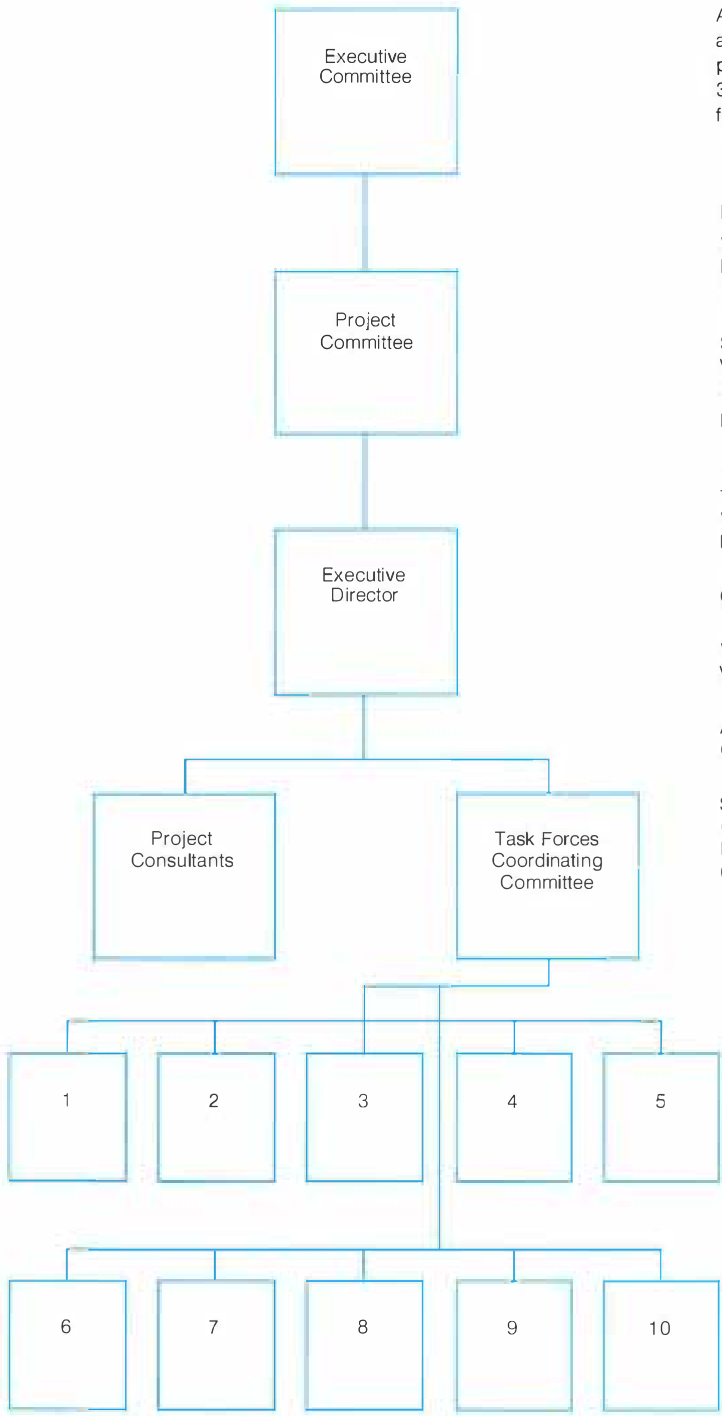
The consequences of altering the basis for electricity pricing are uncertain. Some utility executives and regulators have reservations about plunging ahead because of a lack of knowledge. Caution is warranted because no one can predict with reasonable confidence, much less with certainty, the amount of load shifting that might occur, the amount of energy conservation (if any) that might result, the effect of time-of-day pricing on future generation mix and fuel use, the consequent effect on capital and operating costs, and the subsequent changes in revenue requirements and class-by-class customer charges.

Since these matters are the core of utility finances and corporate viability, it is understandable that utility management is reluctant to dive in without checking the depth of the water below (5). Similarly, various customers or classes of customers are uneasy even before peak load pricing schemes are translated into specific rate schedules (6).

Steps toward resolution

Such great uncertainty and deep anxiety have not paralyzed the regulatory community—nor, for that matter, state and federal legislators (7). For example,

ELECTRIC UTILITY RATE DESIGN STUDY
Organization Chart



A diversity of rate design views, interests, and approaches is ensured with more than 100 people on the 10 task forces, another 25 on the 3 supervisory committees, and 10–12 consulting firms undertaking one or more tasks.

Project Committee

William J. Jefferson (Chairman)
Executive Director of Rates, Research, and Data Control
Consumers Power Co.

Samuel Behrends, Jr. (Vice Chairman)
Vice President, Rates and Regulation
Carolina Power & Light Co.

Herbert I. Blinder
Director of Technical Services
American Public Power Assoc.

Thomas H. Burbank
Vice President
Edison Electric Institute

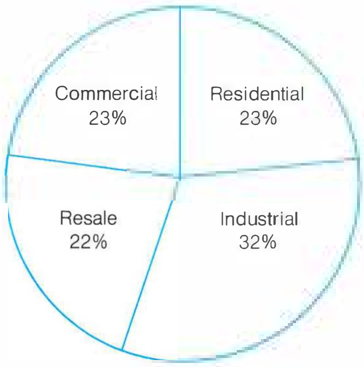
Lowell J. Endahl
Coordinator, Research and Development
National Rural Electric Cooperative Assoc.

William M. Gallavan
Vice President, Rates and Valuation
Pacific Gas and Electric Co.

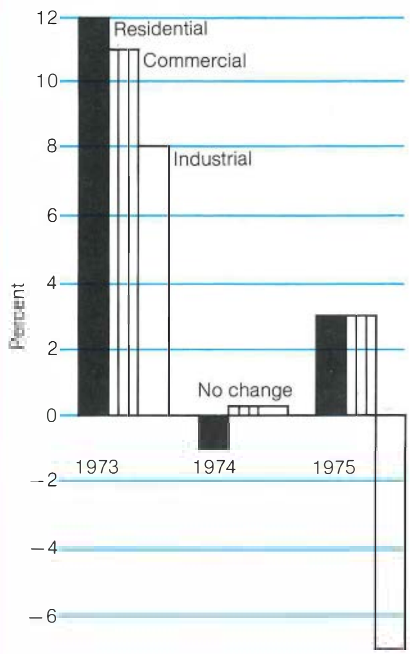
Alfred E. Kahn
Chairman
New York Public Service Commission

Sam H. Schurr
Co-Director, Energy and Materials
Resources for the Future, Inc.
(Consultant to EPRI)

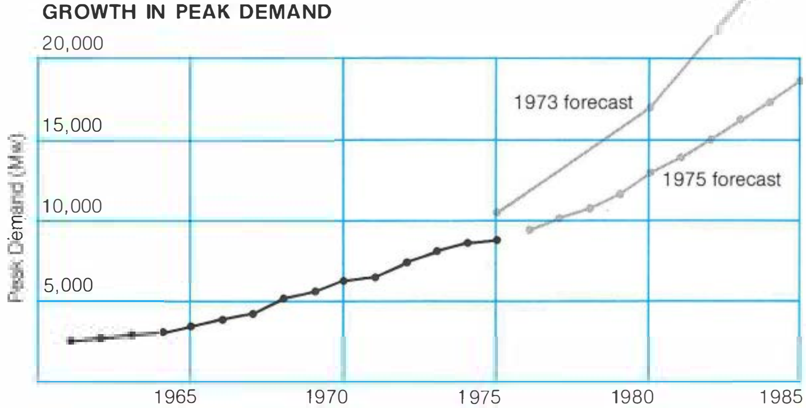
COMPOSITION BY CUSTOMER CLASS, 1974



GROWTH RATES



GROWTH IN PEAK DEMAND



The experience of one utility illustrates how difficult it is to generalize about electricity usage—and therefore about the wisdom or efficacy of rate redesign. For this company in the southeastern U.S., three major customer classes (plus electricity for resale to other utilities) make up its 1974 total sales. The successive—and mixed—impacts of conservation and recession particularly affected industrial electricity usage from 1972 to 1975, as shown by the bar charts of residential, commercial, and industrial sales growth. In turn, this experience yielded two markedly different forecasts of the utility's anticipated peak demand growth for the next nine years.

in a Madison Gas & Electric Co. rate hearing before the Public Service Commission of Wisconsin, the company and the commission thrashed out rate reform issues between 1972 and 1974, including incremental costing, peak load pricing, and rate flattening (*8*).

Similarly, the Vermont Public Service Board, the Central Vermont Public Service Corporation, various local academicians, and the National Science Foundation formed a coalition to study residential demand on a winter peaking system. Their objective is to prepare rates and develop load management techniques for controlling this demand. Time-of-use pricing, the development of heat storage devices and, recently, the installation of ripple controls* have been melded into a modest but working experiment (*9*).

More recently, the drive to reduce uncertainty has taken three directions. First, state regulatory commissions have held extensive generic hearings on rate design issues (e.g., in California, New York, and North Carolina) or have examined design innovations as a part of regular rate cases (e.g., in Virginia and Colorado). Second, the Federal Energy Administration has funded numerous load management demonstration projects to evaluate price and nonprice mechanisms that might foster a balanced growth of electricity usage and peak demand. And third, all segments of the electric utility industry and the regulatory community have joined forces to conduct a searching reappraisal of rate design principles and load management techniques, specifically, the EPRI–EEI study.

Drafting a research plan

Responding to NARUC early in 1975, members of EEI's Rate Research Committee and the Load Research Committee of the Association of Edison Illuminating

*Well-insulated magnesite bricks can be heated electrically to store energy. Such loads could be centrally controlled by signals sent over the power grid. See, for example, the testimony of Professor Thomas Laaspere before the Public Service Commission of New York (Case No. 26806, August 11, 1975).

Companies drafted a research outline. EPRI reviewed the program and, with advice from an economic consulting firm (National Economic Research Associates), prepared a comprehensive plan encompassing 10 research topics. This was approved by EEI and EPRI and then by NARUC. The final *Plan of Study* was published last September.

Concurrently, a research organization was outlined in terms of members, structure, and responsibilities to carry out the *Plan of Study.* Drawn from public, cooperative, investor-owned, and regulatory segments of the utility industry, this organization was approved by NARUC, EPRI, and EEI. By October 1975, the planning and organization phases of the rate design study had been completed.

Organizing the study

In November, two critical, practical efforts began. First, 10 industry-regulatory task forces were staffed and their responsibilities outlined. Second, consulting firms were selected and their scope of work was determined. The roles of these two groups are complementary and are carefully coordinated. Not only will more than one consulting firm address each topic but the task forces will examine closely the findings of each consultant. Moreover, all research results will be appraised by a project committee of highly qualified technical experts.

By the end of 1975, the task forces had held organization meetings, drafted their own work statements, and reviewed research proposals from various economic and engineering consulting firms. Also by year-end, negotiations with several consultants had progressed to the point where work statements and costs had been established.

In brief, the consultants are performing the intensive research specified in the *Plan of Study* (e.g., determining the cost of service for a particular utility and designing specific rates). Task forces are assisting and critiquing the consultants' efforts as well as doing independent work of their own (e.g., gathering and analyzing information on meters).

Study goals and phases

The program is proceeding in a series of five phases to: (1) assess the state of the art and completeness of empirical knowledge; (2) appraise conceptual tools and mechanical equipment presently available; (3) assess what still needs to be developed (e.g., data collection systems, experimentation, and hardware); (4) evaluate the costs and benefits of such development; (5) fashion compromises when costs appear to exceed benefits.

With a budget exceeding $1 million for 1976, the level of funding is adequate for a short-run, intensive investigation of rate design issues. As the study evolves, it is possible that additional research needs will be identified, such as rate experiments, new metering technology, or new utilization equipment. These will be evaluated in terms of cost and likely benefit as follow-on research projects.

First findings: September 1976

Defining the present research under 10 topics is simply for ease of understanding and as a practical division of labor. In fact, the topics are closely interrelated; clearly, as the *Plan of Study* points out, "everything affects everything." Combining and integrating the findings of the various consultants and task forces on all topics will be the major purpose of an overview report, which is slated for submission to NARUC in September 1976. This target date represents a compromise between completeness and timeliness and will enable NARUC to have at least a tentative appraisal of rate design problems before its 1976 annual meeting.

The overview report will present preliminary conclusions, provide summaries and assessments of the research conducted by consultants up to September, discuss task force reports, and make a tentative assessment of the overall results, offering preliminary recommendations.

By early 1977, a final report will integrate the various findings, assess overall results, respond to comments elicited by the overview report, and offer firm recommendations to NARUC about rate design and load management. Thus, with the active support of publicly and cooperatively owned utilities, NARUC, EPRI, and EEI will have examined a very basic question: How should electricity be priced?

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Solid Dielectrics for High-Voltage Transmission Cable

Felipe Garcia

The dielectric integrity of polymeric insulation must be substantially improved if extruded solid dielectric cable is to achieve the reliability and higher voltage ratings available with high-pressure oil-filled cable. Present research is aimed at a better understanding of the mechanisms leading to solid dielectric degradation. ▫ An EPRI technical article

Utilities stand to gain substantial benefits through the use of extruded solid dielectric insulated cables at transmission voltages. The advantages claimed for extruded dielectrics have long since been demonstrated at distribution voltage levels: low cost, low dielectric losses, and ease of handling.

Already the installation and operating costs for extruded dielectric cable are lower than for the very reliable high-pressure oil-filled (HPOF) cables commonly used for high-voltage transmission. For example, the oil storage, pressurizing, and some of the system maintenance requirements of HPOF cable are eliminated. Also, methods for direct burial of extruded dielectric cable by "plowing in" may further reduce its installation cost.

But with present designs, the higher material cost of the thick extruded insulation wall tends to offset lower manufacturing cost (Figure 1). Acceptance of extruded dielectric cable for the higher transmission voltages, therefore, will not take place until certain shortcomings are resolved. Chief among these is the fluctuation in dielectric quality.

Development of consistent quality in extruded dielectrics will permit thinner insulation walls. In turn, this will both lower the initial cost and reduce the degree of thermomechanical stress, a potentially damaging condition that is aggravated by wall thickness.

The dielectric integrity of extruded polymeric insulation, as exemplified by cross-linked polyethylene (XLP), is therefore the focus of this article, although important research is also being conducted on two related problems: the need for reliable splicing methods and protection of the cable from external moisture that may induce electrochemical treeing.

Felipe Garcia is a project manager in the Underground Transmission Program, Transmission and Distribution Division, EPRI.

Dielectric failure rates

The dielectric breakdown of XLP insulation, in common with other dielectrics, is statistical in nature and it has been empirically established to fit well into the Weibull distribution described by

$$\frac{\log[-\log(1-P_1)] - \log[-\log(1-P_2)]}{\log[E_1] - \log[E_2]} = m \qquad (1)$$

In this equation, for a series of tests on a number of samples, the probability of breakdown P_1 at voltage stress E_1 is related to the probability of breakdown P_2 at voltage stress E_2 by the constant m (Figure 2).

One of the more important criteria used for assessing the dielectric integrity of cable insulation is the relationship between the ac breakdown stress and the elapsed time to breakdown. This relationship can be expressed approximately by the empirical equation

$$E_1^n t_1 = E_2^n t_2 \qquad (2)$$

which relates the times required to achieve breakdown t_1 and t_2 at corresponding voltage stresses E_1 and E_2. Plotting the logarithm of stress against the logarithm of time to breakdown (life) results in a straight line whose slope is characterized by the constant n, a measure of cable life.

This equation is illustrated by curves

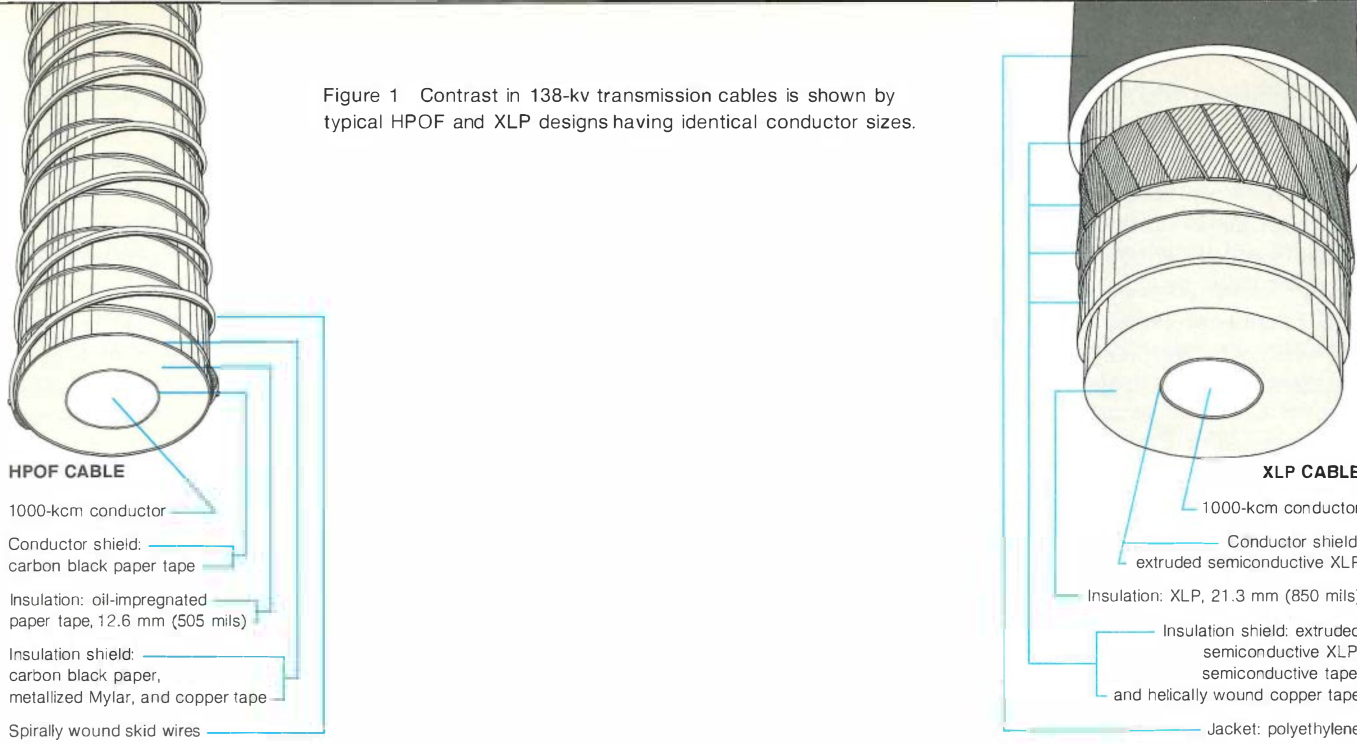

Figure 1 Contrast in 138-kv transmission cables is shown by typical HPOF and XLP designs having identical conductor sizes.

1 and 2 in Figure 3, which show the measured stress/life characteristics of 15-kv cable of recent manufacture (*1, 2, 3*). Curve 3 represents an average of curves 1 and 2. Extrapolation of Curve 3 indicates a breakdown stress (50% probability) of 12 kv/mm for XLP insulation after 30 years of operation.

Although this value is considerably higher than the present average operating stresses of 2 kv/mm (49 v/mil) for 15-kv cable and 3.75 kv/mm (94 v/mil) for 138-kv cable, a more useful assessment of XLP transmission cable reliability would be based on the breakdown probability of full-reel lengths (1500–3000 m) of cable as a function of operating time at normal voltage.

Point A in Figure 3 represents the routine factory test (*4*) performed on all full-reel cable lengths. In this test, cables are subjected to a 60-Hz average stress of approximately 6 kv/mm (150 v/mil) for 5 minutes. The estimated failure rate of 0.5% during this test and Curve 3 can then be used to derive the curves in Figure 4. The curves in Figure 4 are based on a stress/life characteristic $n = 10$ because this value has been experimentally established (*3*) on cable samples

THE INCENTIVE FOR RESEARCH IN SOLID DIELECTRICS

Cross-linked polyethylene insulation for power cables was introduced in the late 1950s (*17*). Since then the trend toward undergrounding utility distribution systems has resulted in rapid adoption of extruded solid polymeric insulation. Its use for distribution cable now substantially exceeds that of the classic solid-type, oil-impregnated paper insulation. At present, the extruded dielectrics most commonly used in distribution cable are: unfilled cross-linked polyethylene (XLP), unfilled polyethylene (PE), mineral-filled cross-linked polyethylene (MFXLP), and filled ethylene-propylene rubber (EPR).

Beginning in the early 1960s, extruded solid dielectric cables were introduced into the transmission voltage range (69 kv and higher) (*18*). Their application at these levels, however, has been slower than at distribution levels, primarily because of the high degree of reliability required for transmission cables.

In an effort to accelerate the development of extruded dielectric materials for use in the high-voltage transmission range, the Electric Research Council in 1968 began a program (assumed by EPRI in 1973) for the development and field testing of extruded dielectric cables rated 138 kv (*19, 20*). Six cable manufacturers participated in this program: General Cable Corp., General Electric Co., Kaiser Aluminum and Chemical Corp., Okonite Co., Phelps Dodge Cable and Wire Co., and Reynolds Metal Co.

With the exception of the mineral-filled XLP dielectric used by General Electric and the EPR used by Okonite, all cables employed an unfilled XLP dielectric. Tests revealed that certain improvements in dielectrics and cable designs will have to be achieved before these cables can be routinely applied at higher voltage levels.

EPRI research efforts today are directed toward the study of mechanisms of degradation and breakdown of extruded dielectrics, methods for enhancing the integrity of these dielectrics, and improvements in cable-manufacturing processes.

with artificially created defects of the types believed present in long cable lengths. Curve 1 indicates that the breakdown probability of full-reel lengths of 138-kv cable of present design ranges from about 3% after 1 year to about 8% after 30 years.

The results presented in figures 2, 3, and 4 cannot be interpreted too rigorously for the following reasons:

- The data for these curves were developed at room temperature, whereas there are indications (*1, 2*) that at the normal operating temperatures of these cables, the stress/life characteristic value of n is substantially greater than 13, hence improving the performance of the cable.
- These data were developed on relatively short cable samples with thin insulation walls, which may tend to give optimistic results.
- The data are based on test durations ranging up to several tens of hours, and there is no evidence to indicate that the mechanism responsible for these breakdowns would also be the cause of breakdown after several years.
- There is insufficient evidence to establish the performance of these cables when subjected to impulse and switching surges after several years of aging under normal operating ac stress.
- Possible aging by environmental conditions is not taken into account.

Nevertheless, the results presented in Figure 4 are a strong indication that the development of thin-wall extruded dielectric cables for operation at 138 kv and higher voltages will require substantial improvements in the dielectric integrity of the insulation.

Influences on dielectric integrity

Although the intrinsic dielectric strength (*3*) of polyethylene is on the order of 800 kv/mm (20 kv/mil), unexplained failures of extruded dielectric cables are being experienced at operating stresses as low as 2 kv/mm (50 v/mil). This apparent incongruity may be explained by the presence of severe defects in the cable insulation. These may be broadly classified in two categories. First are those that serve to greatly increase the normal voltage stress in small localized regions of the cable insulation. They may be sharp protrusions from the conductor shield (or the insulation shield) into the insulation. Or they may be conductive contaminants—solid or liquid—introduced into the insulation during its manufacture or subsequent processing into finished cable.

The second category includes defects that serve to weaken the intrinsic dielectric strength of the insulation. They are generally considered to consist of dielectric contaminants, such as gas- or liquid-filled cavities, or included solids whose intrinsic dielectric strength is lower than that of the surrounding insulation.

Stress enhancement The stress enhancement occurring at the tips of sharp protrusions or whiskerlike conductive contaminants can be sufficiently great to exceed the intrinsic dielectric strength of the insulation and give rise to electrical trees (so named because of their branched, treelike appearance). The branches are microscopic fissures that —either through carbonization of their surfaces or in the course of ionization of included gases—may in themselves act as conductive field-enhancing protrusions and further propagate the tree until catastrophic failure occurs.

Weakened dielectric strength The presence of cavities in cross-linked polyethylene

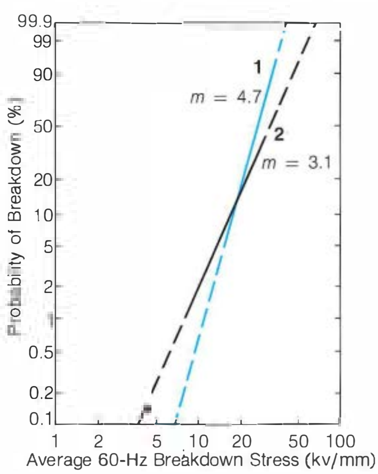

Figure 2 Probability of 1-hour breakdown stress for 15–35-kv XLP cable of recent manufacture falls into the Weibull distribution described by Equation 1. Curve 1 represents 15-kv cable (9-m samples) with 4.4-mm (175 mils) insulation (*1, 2*). Curve 2 plots 15–35-kv cable (15-m samples) with 4.4–8.6-mm (175–345 mils) insulation (*3*).

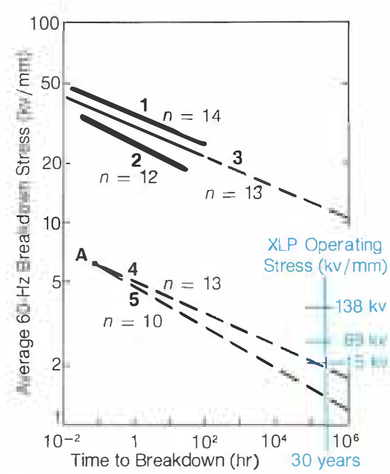

Figure 3 Experimental data of curves 1 and 2 relate breakdown stress (50% probability) and time for 15-kv XLP cable of recent manufacture. Curve 3 is an average of these data, extrapolated to 30 years. Point A represents the standard factory test on full-reel lengths per AEIC 5-74. The estimated failure rate during this test is $\simeq$ 0.5%. Curve 4 is an extrapolation of Point A, using the same n value as in Curve 3. Curve 5 uses an n value of 10 because of experimental findings in samples with artificially created defects of the type believed to be present in long cable lengths.

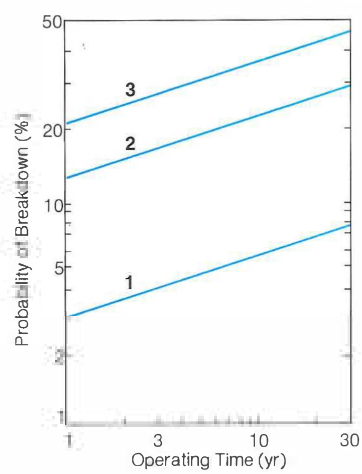

Figure 4 The probability of breakdown for full-reel lengths of XLP cable is strongly dependent on operating stress and operating time. Curve 1 is based on an average operating stress of 3.75 kv/mm (94 v/mil), the present design stress of 138-kv XLP cable. Curve 2 is based on 6.34 kv/mm (158 v/mil), the present design stress of 138-kv HPOF cable; and Curve 3, on 7.8 kv/mm (195 v/mil), the present design stress of 345-kv HPOF cable. All 3 curves are based on n = 10.

is due in part to the semicrystalline nature of this material. Through measurements of crystallinity and apparent density, Matsuoka (*5*) has determined that the relative volume occupied by microscopic fissures formed during the cooling of the polymer from its molten state may amount to as much as 2% in polyethylene. The presence of microscopic fissures between crystalline spherulites in semicrystalline materials has been confirmed by Wagner (*6*). Furthermore, his preliminary findings indicate that electrical breakdown channels follow the boundaries between adjacent spherulites or penetrate through amorphous (noncrystalline) regions.

Voids created by the by-products of the cross-linking agent and by penetration into the insulation of the high-pressure (250 psi) steam commonly used to achieve the cross-linking reaction are generally ellipsoidal in shape and may attain sizes in excess of 100 μm (4 mil). The great majority of voids thus formed, however, are less than 10 μm (0.4 mil) in diameter.

The population density of these very small voids is extremely high. Kageyama et al. (*7*) have measured population densities in the range of 10^5–10^6 per cubic millimeter in steam-cured, cross-linked polyethylene and in the range of 10^3–10^4 in cross-linked polyethylene cured in nitrogen gas or molten metal. These results indicate that penetration of steam during the cross-linking process, with its subsequent nucleation into water globules, may be the primary factor in the formation of microvoids; the gaseous and liquid by-products of the cross-linking reaction may be secondary factors.

The role that microvoids play in determining the dielectric strength of cross-linked polyethylene is not clear. Microvoids filled with liquids of higher relative dielectric constant than the surrounding dielectric may act as stress-enhancers of varying severity, depending on their geometry. The same is true of liquids of relatively low resistivity. Microvoids filled with gases are susceptible to ionization, which can lead to treeing. At normal operating stresses, voids smaller than about 100 μm will not ionize. In the vicinity of stress-enhancers, however, much smaller voids may still be susceptible to ionization.

Bahder et al. (*3*) have shown that cables containing large, artificially created cylindrical voids measuring 0.76 mm (30 mil) in diameter and 1.27 mm (50 mil) in depth exhibit a breakdown voltage approximately 20% lower than cable without voids. Considering the facility with which the gas in these large voids will ionize, such voids do not appear to have too serious an effect on the cable performance. In contrast, Yamada et al. (*8*) indicate that cables with spherical microvoids of maximum diameter ranging from 10 to 20 μm (0.4–0.8 mil) exhibit breakdown voltages that are 45% lower than cables with microvoids of maximum diameter ranging from 5 to 7 μm (0.2–0.3 mil).

Experimental approaches In studying the influence on breakdown of the microscopic structure of XLP insulation and in the development of potential methods for improving this insulation, substantial work has been done in altering its microscopic structure. This has been accomplished through impregnation of the insulation with a variety of gases and liquids, blending of various additives into the insulation prior to its extrusion onto the cable, and through the use of methods other than high-pressure steam for achieving the cross-linking reactions.

Table 1 gives a partial listing of some of the work that has been done in these areas. The preliminary data on samples Ia–c indicate a substantial increase in the stress/life characteristic, *n*, at higher temperatures. The reason for this improvement is not understood. One possible mechanism suggested devolves from the nonhomogeneous nature of the polymer: its differential thermal expansion in localized regions may tend to move material into existing microscopic spaces and effectively decrease their volume. Precisely how such a decrease in volume would affect the stress/life characteristic is not known.

Samples II and III show the influence of gases at various pressures. In general, it appears that cable performance improves at higher gas pressure. A suggested mechanism for this improvement is that gas-filled microvoids are susceptible to ionization, a phenomenon that (for certain ranges of microvoid sizes and pressures) will decrease with increasing pressures. In a similar manner, samples IV and V show the influence of impregnation with a liquid.

Samples VI, VII, and VIII show the influence of various additives blended into the insulation compound before its extrusion on the cable. The action of the so-called voltage stabilizers in Sample VIb is not fully understood; it is suggested that these additives act as electron traps and capture free, energetic electrons that would normally be capable of ionizing the polymer. The organic semiconducting material in Sample VIIb is believed to act by diffusing out of the solid portions of the polymer into gas-filled microvoids and coating the walls of these microvoids with a semiconducting layer. This layer tends to short-circuit the microvoid, thus decreasing the intensity of the voltage stress within it and preventing ionization. The inorganic fillers used in Sample VIIIb are materials that are mechanically stronger than polymers and less susceptible to degradation. It is suggested that they act as physical barriers through which a developing tree cannot propagate.

Samples IXa–d illustrate the effects of changing from the standard pressurized-steam cross-linking process to one employing a nitrogen atmosphere. Samples IXa and IXb seem to indicate that steam indeed penetrates the insulation and when subsequently condensed may act in a manner similar to that of the semiconductive additive of Sample VIIb. When this moisture was removed by evaporation in an oven, the dielectric strength decreased. In contrast, such a decrease did not occur in the samples cross-linked in nitrogen.

The various additives and impregnants

listed in Table 1 serve either to heal defects that occur during manufacture or to strengthen the surrounding polymer against the degrading effects of those defects. In a practical system the additives must remain active during the required lifetime of the cable, must not be lost from the insulation through diffusion processes, and must have no harmful effects on the remainder of the cable structure. Similarly, impregnants must function without compromising the basic simplicity of XLP cable. Gaseous or liquid impregnants that might require pressurizing would result in more expensive installations analogous to HPOF cable systems.

An alternative to healing defects in the insulation is to decrease their magnitude or their frequency of occurrence during manufacture. Cross-linking in nitrogen is one example of such a method. Other work in this area includes a joint EPRI–ERDA project (*15*) to develop methods for the purification of insulating material by extracting all but the most minute contaminants before extrusion. This project also seeks to attain a more uniform dispersion of the required cross-linking and antioxidative agents and to cross-link the extruded insulation in a high-pressure ambient free of steam.

Another method to achieve cross-linking is through the use of high-energy electron beams. Such a system eliminates the need for the chemical cross-linking agents normally blended into polyethylene. It also eliminates the need for high-pressure steam or other hot curing ambients. Developmental work on a high-energy electron irradiation cross-linking system is presently underway in an ERDA-sponsored project (*16*).

Research directions

The economic benefits that would accrue to utilities through the use of extruded dielectric transmission cables provide ample incentive for further research and development. A considerable effort is being expended worldwide to gain a better understanding of mechanisms of degradation of extruded dielectric cables, to develop improved manufacturing methods, and to develop simplified, more reliable splices and other installation components. With these advances, extruded dielectric cable should offer the reliability and higher voltage ratings of HPOF transmission systems.

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2. EPRI–ERDA project: EPRI RP7808; ERDA E(49–18)–1422. Mechanism of Breakdown of Cross-Linked Polyethylene Insulated Cable. Contractor: Phelps Dodge Industries, Inc.

3. G. Bahder, G. S. Eager, D. A. Silver, and R. F. Lukac. "Criteria for Determining Per-

Table 1 **INFLUENCE OF IMPREGNANTS, ADDITIVES, AND MANUFACTURING PROCESSES ON THE AC BREAKDOWN VOLTAGE STRESS**

Ref.	Sample No.		Cable Dimensions: Conductor Size	Insulation Thickness mm	(mils)	Test Length m	(ft)	Sample Preparation and Test Conditions
1, 2	I	a	4/0 AWG	4.4	(175)	9.1	(30)	Control sample tested in air at 30°C and atmospheric pressure
1, 2		b	4/0 AWG	4.4	(175)	9.1	(30)	Same as Ia but tested at 70°C
1, 2		c	4/0 AWG	4.4	(175)	9.1	(30)	Same as Ia but tested at 90°C
1, 2	II	a	4/0 AWG	0.75	(30)	0.032	(0.11)	Control sample tested in air at standard temperature and pressure
1, 2		b	4/0 AWG	0.75	(30)	0.032	(0.11)	Same as IIa but pressurized and tested with air at 3 atmospheres
9	III	a	200 mm²	4.0	(157)	—	—	Control sample tested in air
9		b	200 mm²	4.0	(157)	—	—	Same as IIIa but impregnated with SF_6 gas and tested at 3 atmospheres
1, 2	IV	a	4/0 AWG	4.4	(175)	9.1	(30)	Control sample tested in air
1, 2		b	4/0 AWG	4.4	(175)	9.1	(30)	Impregnated with diethylene glycol
1, 2		c	4/0 AWG	4.4	(175)	9.1	(30)	Impregnated with triethylene glycol
10	V		100 mm²	7.7	(303)		·	Hollow conductor filled with silicone oil
11	VI	a	100 mm²	3.0	(118)	—	—	Control sample
11		b	100 mm²	3.0	(118)	—	—	Same as VIa but with 3 voltage stabilizers blended in.
12	VII	a	250 mm²	14.7	(579)	...	...	Control sample
12		b	250 mm²	14.7	(579)			Same as VIIa but with organic semiconducting material (unspecified) blended
13	VIII	a	2/0 AWG	3.8	(150)	9.1	(30)	Control sample
13		b	2/0 AWG	3.8	(150)	9.1	(30)	Same as VIIIa but with inorganic filler (unspecified) blended in
14	IX	a	100 mm²	6.0	(236)	—	--	Steam-cured control sample
14		b	100 mm²	6.0	(236)			Same as IXa but oven-treated to remove volatiles from cross-linking process
14		c	100 mm²	6.0	(236)	...	...	Cured in a hot pressurized-nitrogen atmosphere
14		d	100 mm²	6.0	(236)	...	...	Same as IXc but oven-treated to remove volatiles from cross-linking process

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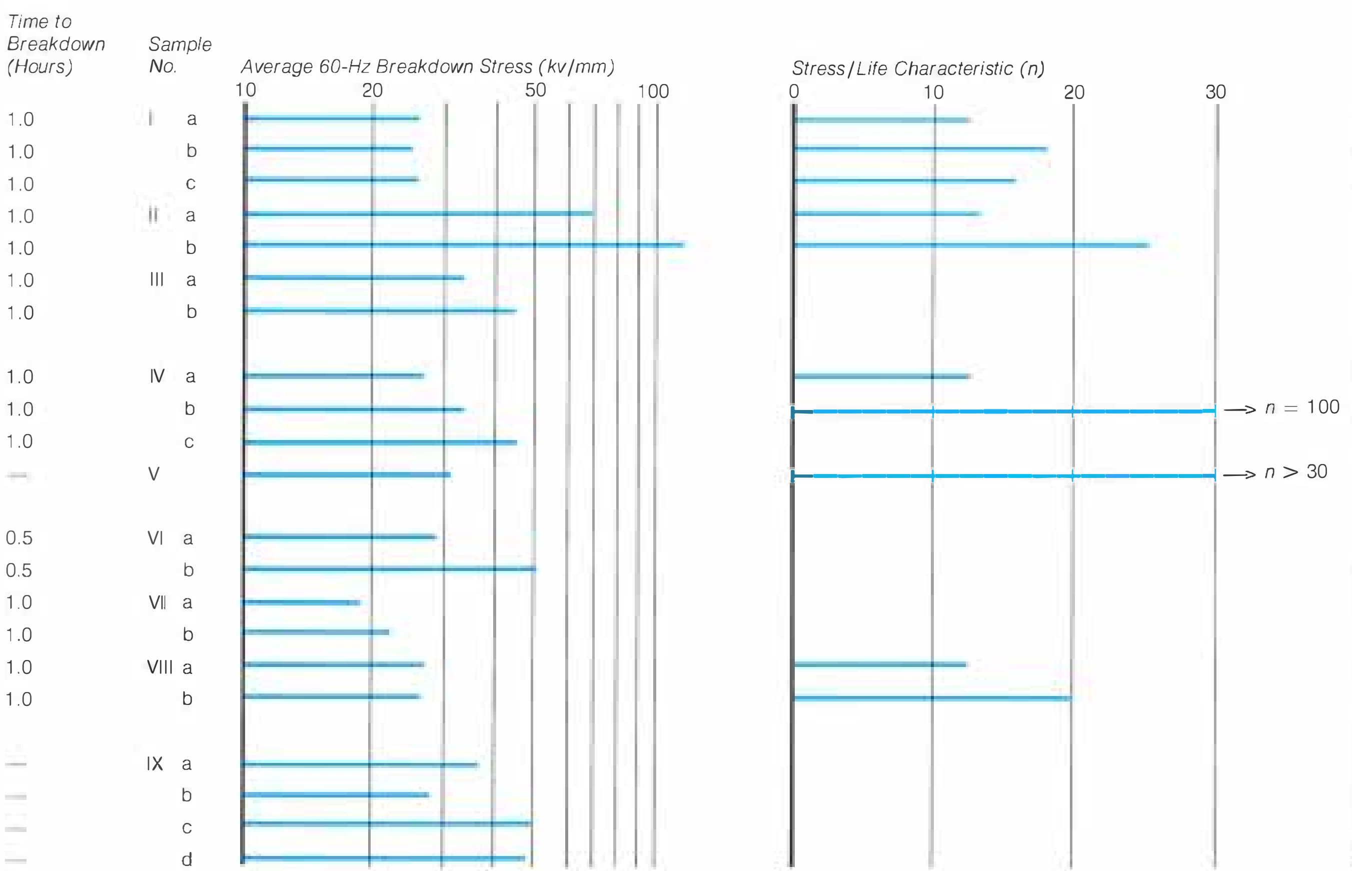
AND STRESS/LIFE CHARACTERISTIC OF CROSS-LINKED POLYETHYLENE INSULATION



Fossil Fuel and Advanced Systems Division

Richard E. Balzhiser, Director

Fossil Fuel Department

LIQUEFACTION PROGRAM

An ever-increasing need for liquid fuels has been evident in the electric utility industry in recent years. In the United States, 19% of electric power is generated with liquid fuels, all of which are now petroleum-derived products. The utility industry's preference has been to provide its peak service with gas- or petroleum-distillate-fueled turbines and to use coal-fired and nuclear systems primarily for baseload service.

A powerful stimulus for the installation of liquid-fueled utility systems has been the air pollution standards promulgated by federal and state environmental protection agencies. Clean liquid-fired plants have been the cheapest and easiest way to meet sulfur oxide and particulate standards.

Where peaking and intermediate loads must be met, the turbine is an ideal utility choice because it has the lowest capital cost per kilowatt hour delivered of any installed system. Furthermore, since it burns clean fuel, there is no need for expensive cleanup systems, such as scrubbers, which would be idle most of the time.

To cope with near-term peaking requirements, many utilities are installing either combustion turbines or combined-cycle units, which require clean liquids for their firing. With the limited capital available, the difficulty in siting nuclear and coal-fired power plants, and the extremely long time required to bring a nuclear plant on stream, combined-cycle units or combustion turbines are a very practical choice. The supply of fuel required for these devices, however, is limited. Utility investments in this new equipment and in existing oil-fired units demand that a secure supply of clean liquid fuel be available.

The EPRI Liquefaction Program addresses this need by helping to develop the technology to provide clean liquid products from coal. When compared with other means of pollution control, clean liquids offer several benefits for utility systems. One major benefit is that the utilization of fuel is not directly coupled to the fuel cleanup process so coal liquefaction plants can be located at optimum sites rather than at the power plant, as would be the case with stack gas scrubbing and coal gasification units. Another benefit is that liquids can be fired directly in existing oil-fired plants without major plant modification. In addition, the cost of transporting energy may be less for liquids than for other materials, such as coal.

Bringing Liquefaction to Commercial Reality

The development of liquefaction technology cannot be addressed with a single product objective in mind because different regions of the U.S. must meet different sulfur, nitrogen, and particulate standards for their power plant fuels. Consequently, the EPRI program is geared to developing processes that can produce solid products, such as solvent-refined coal (SRC)—which is a solid at room temperatures and therefore can be used as a clean substitute for coal—heavy or light fuel oil, and fuel-grade methanol.

Liquefaction must be able to compete with petroleum-derived feedstocks before it can become a commercial reality. The price of oil will continue to increase as supplies diminish and the amount used by the rest of the world approaches U.S. levels. Coal liquefaction, however, does not offer the promise of a cheap fuel. Current estimates, which are largely based on a coal cost of about $1 per million Btu and capital investments of $10,000–$20,000 per daily barrel of product, result in fuel costs on the order of $3–$6 per million Btu, depending on fuel quality.

In order to take advantage of the economies of scale in an expensive coal liquefaction plant, a typical plant would process approximately 25,000 tons per day to produce 50,000–60,000 barrels of fuel per day. A 1000-Mw generating plant would consume about 30,000 barrels per day.

Major Thrust of Liquefaction Program

The major thrust of the EPRI program is to support projects that bring large pilot plants into operation, because only at that level can processes be judged for their operability, potential for commercialization, and overall economics. Since some liquefaction projects will be much more successful than others, EPRI believes the best way to ensure cost-competitive liquefaction development is by examining a variety of promising processes and supporting a number of different projects.

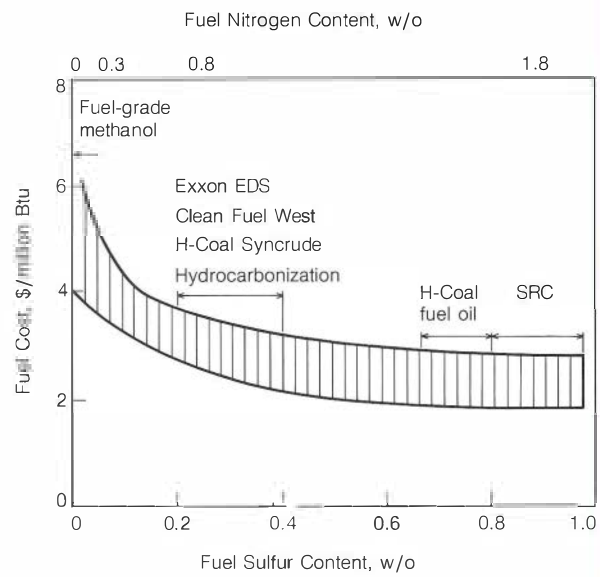
Fuel Costs

The estimated fuel costs in processes being developed with EPRI support (or currently being considered for support) are presented in Figure 1 as a function of the fuel sulfur and nitrogen content. All the projects listed include a large-scale, pilot plant phase of 200—2000 tons per day to be operational in the 1978–1982 time frame. Prime candidates for commercialization can then be selected on the basis of how well these plants operate and the projected cost of the liquid products.

Other significant R&D work includes methanol synthesis, which may provide an excellent turbine fuel for peaking requirements because it contains no sulfur, nitrogen, or particulates. Current projections on high-purity methanol from coal range from \$5 to \$10 per million Btu. Both the gasification step to produce a mixture of carbon monoxide and hydrogen (which is then converted to liquid) and the synthesis reactor in which the reaction occurs may be significantly improved in the near term so that the overall cost of fuel-grade (low-purity) methanol can be lowered.

Parallel with projects for large-scale pilot plant demonstrations, EPRI has a strong program underway in process analysis and technology development to help lower product prices. The cost of liquid products from coal can be lowered through two methods: lower plant investment requirements and improved hydrogen utilization.

Figure 1 The cost of processing liquid fuels from coal and demonstrated successful pilot plant operation will help determine prime candidates for commercialization.



Solid Separation

Solid separation is one of the most costly steps in a liquefaction flow sheet. Currently, filtration is considered the prime candidate for solid separation when heavy fuel oil or SRC is made. It may, unfortunately, also turn out to be the most mechanically complex and expensive. EPRI-sponsored research by Johns-Manville is underway on an improved filter that may substantially increase the capacity of single filters.

Other EPRI projects are considering alternative means of solid separation that can be used independently or in concert with one another to develop an optimum solid separation system.

A new research project will help develop improved centrifuges for liquefaction systems. Under an EPRI contract, the Massachusetts Institute of Technology is examining magnetic separation to separate sulfur-containing pyritic material from liquefied coal. The end product is a low-sulfur, solids-containing liquid or solid fuel that can be used as a feed to an existing boiler having an electrostatic precipitator.

The most promising area for solid separation has unfortunately had the least large-scale development to date. It involves using either special solvents or applications of solvent de-ashing technology to separate ash and unconverted coal from the heavy liquid produced. The technique offers the potential for mechanical simplicity, low investment, and excellent integration with hydrogen production facilities. Significant research efforts in this area should be underway this year at the Wilsonville, Alabama, SRC test facility.

Basic Reaction Mechanisms

EPRI research on basic reaction mechanisms under separate contracts with Mobil Research and Development and Gulf Research and Development shows encouraging initial results, indicating improvements can be made through lower reaction volume requirements and improved hydrogen utilization. In another contract with Mobil and in one with Arco, extensive research is being conducted into product upgrading.

Hydrotreating, solvent deasphalting, and chemical action are being examined for their upgrading potential.

Hydrogen Utilization

Each liquefaction plant should be able to generate its own hydrogen from coal or from liquefaction residues. This allows lighter and more valuable products, such as gas and naphtha, which would normally be used for hydrogen generation, to be sold commercially as by-products. Under an EPRI contract with Texaco Research and Development, demonstration efforts are underway to show that liquefaction residues can be gasified to produce hydrogen without operating difficulty.

Equipment Development

Key areas subject to frequent failure are the charge pumps and the letdown valves. Because of their relatively unreliable performance, the costs related to both systems are high. Battelle, Columbus Laboratories is examining the letdown valve problem, and additional studies are being planned.

Substantial cost benefits can be achieved by optimizing hydrogen use. Some of the processes EPRI is studying involve catalysts in the liquefaction reactor to carry out the basic hydrogenation step.

A project with Amoco Research and Development is aimed at developing improved catalysts that can carry out the liquefaction reaction and produce more desirable products at lower pressures. Lower hydrogen consumption would save both investment and operating costs in the hydrogen generation facility as well as in the liquefaction plant.
Program Manager: Ronald H. Wolk

Advanced Systems Department

WATER-COOLED ULTRA-HIGH-TEMPERATURE GAS TURBINES

Since the early 1960s, gas turbines (also referred to as combustion turbines) have had large-scale electric utility use, especially in peaking applications. As turbine inlet temperatures and compressor pressure ratios and efficiencies increased, so did performance capability. This improvement was facilitated by the extensive research and development effort originally sponsored for aviation use of gas turbines.

Increased turbine inlet temperatures were made possible by improved high-temperature alloys and especially by better techniques for cooling turbine components. Developed for aircraft use, these techniques involve film and transpiration cooling in which the compressor discharge air is forced through tiny holes on the surface of the blades and vanes, forming a cooling barrier that lowers the temperature of these components hundreds of degrees below the hot combustion products. Some new utility turbine models use film cooling.

Fuel Compatibility of Utility Gas Turbines

The transfer of aviation cooling techniques to utility application is not, however, necessarily optimal because these cooling techniques are sensitive to lower-quality fuel where ash and contaminants can clog cooling holes. While this is not a major problem in aviation use because of the high-quality aviation grade fuel, utilities normally use lower-grade distillates and are likely to depend on residual oil- and coal-derived fuels in the future. Developing methods for accommodating these lower-grade fuels and improving reliability and increasing performance are the primary goals of EPRI's gas turbine program. At this time a project with General Electric Co. (RP234) to develop a water-cooled ultra-high-temperature gas turbine appears to hold the greatest promise for achieving these goals.

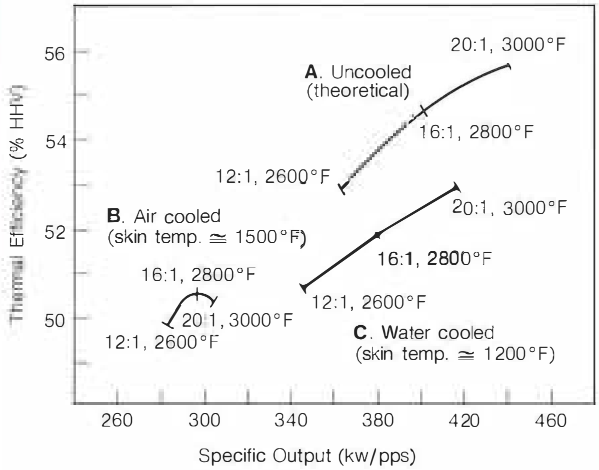
Advantages of Water Cooling

Water cooling is precluded from aviation use because of weight, but this is not a primary consideration in utility use. Water is a very effective coolant and, unlike air, requires negligible pumping power to be pressurized up to and beyond the turbine inlet pressure. Water can cool turbine components to temperatures below the point where corrosion, deposition, and erosion become major problems, even when using fuels of the poorest quality. The main application for water-cooled gas turbines is expected to be in gas turbine/steam turbine combined cycles for use in intermediate base-load service. Water requirements for gas turbine cooling are much less than for the steam turbine condenser and makeup feedwater.

These performance considerations are quantitatively reviewed in Figure 2. The curves show the efficiency of the gas turbine/steam turbine combined cycle as a function of power per unit airflow, with turbine inlet temperature and pressure ratio as parameters. Curve A indicates the ideal case where no cooling is used. Curve B represents air film cooling techniques to hold maximum metal temperature to 1500°F. Above that temperature, corrosion becomes a problem, even when "clean" distillate fuel is used. Curve C shows a water-cooled engine with metal temperature held below 1000°F. At this temperature, indications are that corrosion, deposition, and erosion can be minimized, even when such dirty fuels as residual or synthetic fuel oil from the H-Coal process are used.

Figure 2 shows that water cooling (with 1000°F metal temperature) does allow higher efficiency than air cooling, even with 1500°F metal temperature. Air cooling at 1000°F would be impractical. The water-cooled engine has a much higher power per unit airflow than the air-cooled engine—almost approaching the ideal uncooled case. Although the ancillary equipment needed for water cooling can be costly, the fact that capital costs tend to be proportional to airflow indicates a lower capital cost for the water-cooled engine. These benefits have been the motivation for EPRI's development of water-cooled, ultra-high-temperature gas turbines, and this project is the first to be directly oriented to utility use from its inception, rather than being based on aviation technology.

Figure 2 Comparison of performance of combined cycle utilizing uncooled (Curve A, theoretical), air cooling with skin temperature to 1500°F (Curve B), and water cooling with skin temperature kept below 1200°F (Curve C). Specific output of the water cooled practically matches the theoretical uncooled, while the air cooled has a much lower specific output and much lower efficiencies, especially at the higher operating temperatures.



Research Background

Early investigations of closed-circuit water cooling were unsuccessful. In 1967 General Electric began to investigate open-circuit cooling with the water free to leave at the bucket tip. By 1973 General Electric achieved successful operation of a small-scale demonstrator water-cooled gas turbine operating at gas temperatures up to 3500°F with pressures up to 16 atmospheres.

Encouraged by the success of the small-scale turbine, EPRI contracted with General Electric to demonstrate the feasibility and to evaluate the performance and economic value of a complete utility-size commercial machine (RP234). The first of the three project phases (completed in March 1975) dealt with the preliminary design for a full-scale engine and the identification of certain problems to be solved prior to construction of a prototype. In the current phase, General Electric is attempting to solve these problems before work begins on the design, development, fabrication, and testing of a full-scale prototype.

A final report, *Assessment of a Water-Cooled Gas Turbine Concept,* was recently published by EPRI. It details the following developments.

- Preliminary design of a complete ultra-high-temperature water-cooled machine. Although comparable to current machines, this machine will have hot gas path components operating at much lower temperatures.

- Evaluation of performance, cost, and operational problems. This evaluation indicates 48% HHV efficiency (in combined cycle) 370 kw seconds per pound from liquid fuel.

- Identification of technological problems. These problems are in areas of water erosion; water metering, distribution, and recovery; water-cooled nozzle, bucket, and transition piece design, development, and testing; and combustor and controls development for low-Btu coal gas.

Current Developments

Some experimental results from the current phase of the General Electric project have recently been obtained. It was found, for example, that the combustion product deposition would be far less in the water-cooled turbine than in conventional machines and it could be far more easily removed. Corrosion has been shown to be much less at metal temperatures below 1050°F than above 1175°F, even with the poorest-quality residual petroleum fuels. Water channel erosion is not a problem when steel or nickel channels are used, but copper is severely eroded. The project also demonstrates that with partial channel flow, the water still tends to wet the entire cooling channel perimeter because surface tension overcomes the Coriolis force. Consequently, designs will use partial channel water flow.

Another major effort in the current phase of this project has been in the design analysis of turbine buckets, blades, and nozzle partition vanes. The design of the rotor bucket cooling system is critical to the overall concept. The rotating bucket uses open-circuit cooling instead of the closed-circuit technique used for the stationary nozzles. Closed-circuit cooling of rotating components proved impractical in previous experiments because of the high internal pressures caused by the centrifugal field. The thick coolant passages that would be required to withstand this pressure would lead to thermal stress problems and would not fit into the airfoil shape of the turbine bucket. Further, solid material in the water would be precipitated, tending to clog the passages.

Open-circuit cooling is advantageous in that the water flows naturally and with considerable force in the direction of the centrifugal force. It also has the important advantage that the water flow can be controlled and directed with precision, which experience has shown to be essential to success. However, the problem of collecting the water issuing from the tip of the rotating blade toward the stationary shroud is introduced. A key goal of the current program is the development of ways to collect the water while minimizing both water loss and erosion of the stationary shroud so that it has an acceptable lifetime.

In order to have a prototype engine ready for tests by 1981 or 1982, this program will require a much higher level of funding. ERDA is now evaluating General Electric's proposal for such funding under the new ERDA High-Temperature Turbine Technology Program. The purpose of this program is similar to the EPRI program—developing advanced performance gas turbines for coupling with coal-derived low-Btu gas or liquid fuels. Should ERDA decide to participate in this program, close coordination with EPRI is anticipated. *Project Manager: Arthur Cohn*

FUEL CELLS

A fuel cell converts the fuel's chemical energy directly to electric energy by an electrochemical process that is not subject to the Carnot cycle limitation of thermal machines. Thus, the fuel cell offers a highly efficient and environmentally acceptable means of power generation.

The fuel cell power plant generally consists of three major subsystems—a fuel processor, a fuel cell power section, and a power conditioner. The fuel processor converts a conventional utility fuel to hydrogen gas that can be used by the power section. The power section electrochemically converts hydrogen and oxygen (from the air) to water as it produces dc power. The power conditioner converts the dc power to ac power compatible with an electric utility bus. Among the advantages of a fuel cell power plant are environmental compatibility (negligible emissions, quiet operation, water conservation); high efficiency over a wide range of loads (the fuel cell becomes more efficient than conventional generators at decreasing loads); modular design to permit expansion; and the capability of use in a number of roles within the utility system and adaptability to a wide range of future fuel scenarios. Potential benefits of fuel cell application in a utility system are shown in Table 1.

In 1971 the electric utility industry recognized the potential of fuel cell power plants and initiated a program to determine the viability of fuel cells in an electric utility system. In 1972 that program was separated into (1) the FCG-1 program sponsored by nine utilities and United Aircraft Corp.—now United Technology Corp. (UTC)—and (2) a project sponsored by EEI and UTC. The FCG-1 program was to bring a first-generation, 26-Mw fuel cell power plant into commercial service by 1980. The UTC program, recognizing the somewhat limited applications of the first-generation device, sought the technological advances necessary to broaden fuel cell application beyond the near-term needs of environmentally constrained utilities to a power generator that could be beneficial to the utility industry in a wide variety of roles.

EPRI inherited the electric utility industry's program with UTC to develop a second-generation fuel cell power plant technology capable of a 7500 Btu/kwh heat rate, a $175/kw (1974 dollars) capital cost, operation with a wide range of future utility fuels, and commercialization by 1985 (RP114).

In 1974 EPRI implemented a comprehensive five-year fuel cell plan that would broaden EPRI's role by addressing five issues critical to achieving the objectives of the second-generation fuel cell power plant. These issues or questions include the following.

- The success of the FCG-1 (first-generation fuel cell) effort is a prerequisite to a second-generation fuel cell program. Without government participation, success of the FCG-1 program could not be assured. Thus, the EPRI plan reflected the need for EPRI to obtain government support for a national fuel cell program and then to participate with the government in an early demonstration of the FCG-1 technology.

- The cost/availability of fuel cell fuels in the near-to-mid-term was of major importance in determining the role of fuel cells in the utility network. In October 1974 a contract was released to Arthur D. Little, Inc., (RP318) to develop fuel cell fuel scenarios and favorable means of integrating these within utility systems.

Table 1

POTENTIAL BENEFITS FROM THE APPLICATION OF FUEL CELL POWER PLANTS TO A UTILITY SYSTEM

Fuel Cell Characteristics	*Potential Benefits*
Environmental compatibility	Dispersed generation close to load: Deferred transmission Reduced transmission loss Waste heat utilization
High efficiency over wide range of loads	System load following Efficient spinning reserve
Modular design	Reduced reserve margin Factory assembled Incremental capacity expansion
Versatile operational and fuel capability	Compatible with wide range of future fuel scenarios: Hydrocarbons Coal-derived clean fuels Hydrogen Coal gasifier integration
	Can be considered in wide range of roles: A dispersed peaking generator on liquid fuels A central station baseload generator on coal

□ The technoeconomics of fuel cells in a utility network require delineation. Of primary importance is a quantification of the benefits described in Table 1, as well as a definition of the potential fuel cell market as a function of capital cost. Since these results are somewhat contingent on the fuel scenarios, this effort was scheduled to follow the completion of the fuel assessment project. Public Service Electric and Gas Co., New Jersey, will provide these assessments (RP726).

□ The participation of at least one other fuel cell manufacturer/developer was desired in the development of a second-generation fuel cell power plant. Since the UTC fuel cell technology had been sufficiently superior and the market sufficiently uncertain, other manufacturers were reluctant to participate. However, after discussions with several possible developers, EPRI initiated a project with Exxon Enterprises (RP584) to assess the potential of the Alsthom-Exxon alkaline fuel cell technology to meet the second-generation objectives.

□ A matrix of technology programs is necessary to maximize the probability of achieving the second-generation technology goals. The more viable second-generation fuel cell concepts include the phosphoric acid, molten carbonate, and alkaline technologies.

The phosphoric acid fuel cell is being developed for FCG-1. However, a significant catalyst breakthrough would be required to achieve the second-generation goals. To stimulate this breakthrough, three projects are underway to deal (partially, at least) with phosphoric acid catalytic-electrode improvements.

The molten carbonate fuel cell has been and will continue to be the major focus of the UTC program. A separate project is underway with Northwestern University (RP371) to support molten carbonate electrode development.

The alkaline fuel cell is being addressed under a contract with Exxon Enterprises (RP584). In support of this project, Giner, Inc., assessed techniques for removing CO_2 from the fuel stream (RP391).

The five-year EPRI fuel cell plan has been in effect for about a year. Progress to date can be summarized as follows.

ERDA is now implementing a significant fuel cell program and probably will participate with EPRI in a major FCG-1 demonstration. EPRI has had a major role in obtaining this government support for fuel cells.

Arthur D. Little, Inc., has identified low-sulfur distillate as the best mid-term fuel option. In the longer term, methyl fuel from coal is attractive. However, somewhat surprising were the very attractive scenarios for integrated fuel cell/coal gasifiers fueled directly by coal wherein overall efficiencies of approximately 45% were projected. These results have defined a central station coal-fired fuel cell as a second major application of fuel cells (in addition to dispersed fuel cell generators).

The molten carbonate fuel cell technology has demonstrated nearly 10,000 hours of life in small cells and 1-ft^2 multicell stacks have operated successfully for 1000–2000 hours. Present capability is a projected capital cost of \$225/kw (1974 dollars) at a heat rate of 7500 Btu/kwh. An advanced dc/ac inverter developed under the UTC project (RP114) has been adopted by the FCG-1 program.

All the necessary elements of a coordinated and focused program to implement the second-generation technology are in place. The success of the fuel cell as a utility power plant will now depend on future R&D progress. *Project Manager: Arnold Fickett.*

Nuclear Power Division

Milton Levenson, Director

In the first issue of the JOURNAL we described projects within the Water Reactor System Technology Program. In this issue we will cover projects from the other three nuclear program areas.

□ The Reliability, Availability, and Economics Program includes:

Component Technology
Plant Operations
Plant Chemistry and Corrosion
Diagnostics and Evaluation
Instrumentation and Control
Plant Materials and Processes

□ The Fuels, Waste, and Environment Program covers:

External Fuel Cycle
Plant Decontamination
Radiation Monitoring and Control
Fuel Rod Performance
Halden Fuel Test Program
Plutonium Recycle
Core Performance

□ The Developing Applications and Technology Program involves:

Liquid Metal Fast Breeder Reactor
High-Temperature Gas-Cooled Reactor
Gas-Cooled Fast Breeder Reactor
Advanced Design and Application

RELIABILITY, AVAILABILITY, AND ECONOMICS

Evaluation of Defect Characterization by Ultrasonic Holography

Through the development of ultrasonic holography, it is hoped that an ultrasonic imaging device will be available for use during preservice and inservice inspections of the primary pressure boundary. The objective of RP605 is to determine the ability of ultrasonic holography to accurately characterize defects (e.g., size, shape, orientation, location, and type) in thick section welds.

To relate the results of this research to current practice, the defects will also be characterized by ultrasonic techniques given in the ASME Boiler and Pressure Vessel Code, Section XI; radiography; and destructive examination. Defects will be inspected in production vessel welds, experimental vessel welds, specially prepared samples, and an existing set of special test blocks. The ultrasonic inspections will be performed in accordance with the ASME code by three independent teams. It is expected that one team will be from the UKAEA Risley Engineering and Materials Laboratory to evaluate the ultrasonic B-scan inspection method.

The Babcock & Wilcox Lynchburg research center is the prime contractor for this two-year effort. *Project Manager: Gary J. Dau*

Study of Remote Multiplexing for Nuclear Power Plant Applications

Because of reduced wiring costs, increased reliability, and the potential for modularity and expandability, remote multiplexing systems (RMS) are being offered as an alternative to conventional hardwired systems in collecting data and transmitting control signals throughout nuclear plants. The objectives of RP513 are to provide the utilities with detailed information about major aspects of RMS, to develop a guide for RMS specifications, and to identify technical problem areas associated with RMS that might be suitable for additional R&D effort.

The study includes tasks designed to (1) review the state of the art of commercially available RMS and their application both within and outside the utility industry; (2) document the signal requirements of various generic types of modern power plants; (3) establish different RMS application categories on the basis of complexity and reliability; (4) evaluate the reliability and the technical and cost-benefit aspects of generic RMS in each of the application categories; and (5) develop a guide for RMS specification.

United Engineers and Constructors, with strong capability in power plant instrumentation, control, and wiring requirements, was selected as the primary contractor. TRW, Inc., with technical experience in the analysis, design, and construction of similar complex communications systems, was selected as the secondary contractor. A utility technical advisory group has been established to provide guidance for this project. *Project Manager: A. B. Long*

Documentation of Utility Experience with Process Computers in Power Plants

The reliance on process computers for the surveillance and operation of power plants has increased dramatically as the complexity of these plants has grown to meet demands for greater availability, efficiency, and safety. In the past a plant process computer has not always been deemed essential; therefore, its failures tended to be overlooked. However, this will not be the case for advanced systems because any inadequacies could have serious implications for plant operation. Therefore, it is essential that experience be documented to provide the utilities and EPRI with a better understanding of the problems associated with specifying, procuring, installing, operating, maintaining, and upgrading process computer systems. Under RP618 Macro Corp. will collect technical information through questionnaires and interviews on major process computer systems in power plants. Qualitative data on the successes and problems with implementation and operation will also be collected from various levels of utility personnel. This study will result in (1) a compilation of existing process computer types and applications within power plants, which should facilitate the exchange of information between utilities; (2) a documentation of the utilities' experience with procurement, operation, and maintenance of these systems, which will be helpful in planning future projects; and (3) a summary of the present status of process computer application in power plants, which can be used to plan and evaluate future R&D efforts in this field. A utility technical advisory group will assist with the direction of this project. *Project Manager: A. B. Long*

Sensor Time Response Verification

A key assumption in reactor safety studies is the ability of the reactor protection system to sense the onset of an abnormal transient condition and initiate reactor shutdown before design parameters are exceeded. Heretofore, critical protection system time response characteristics have been periodically verified in actual plant systems from the sensors' outputs, through the logic train, and by trip actuators. Despite their critical role in the overall protection scheme, the sensors themselves have been historically precluded from these tests due to the technological problems associated with precise in-situ measurement.

In this one-year project (RP503), three contractors will investigate and demonstrate the feasibility of the most promising approaches to in-situ sensor time response verification. Babcock & Wilcox will endeavor to apply noise analysis techniques to identify temperature, pressure, and differential pressure sensor time constants, using taped noise data obtained from a Duke Power reactor unit. Nuclear Services Corp. will design and test a hydraulic signal generator that can measure the responses of pressure and of differential pressure transducers currently used by the nuclear industry as protection devices. The University of Tennessee will assess the feasibility of using the loop current step response (LCSR) method for resistance temperature detector (RTD) response verification. The LCSR method entails the use of the RTD sensor element as an ohmic heat source to stimulate the sensor configuration. In principle, heat transport through the element, its well (if applicable), and into the process fluid can be directly monitored to infer the associated time response characteristic. *Project Manager: David Cain*

MEKIN: MIT–EPRI Nuclear Reactor Core Kinetics Code

The computer code MEKIN has been developed by the Massachusetts Institute of Technology for EPRI under RP227 (*1*). This affords the nuclear industry a publicly available, benchmark computation capability for analyzing reactor core transients.

MEKIN provides an analysis of space-dependent transients in light water cooled and moderated nuclear reactor cores. Specifically, MEKIN models thermal, hydraulic, and neutronic phenomena in boiling water and pressurized water reactor cores. These models treat three-dimensional configuration space (cartesian geometry) and time. MEKIN also performs the static calculations required to establish initial reactor conditions and provides options to treat the following effects:

- One or two neutron energy groups
- Zero-to-six delayed neutron families
- Equilibrium xenon
- Motion of control rods, which enter the core from top or bottom, simulating drive-out and scram
- Feedback to neutron cross sections from coolant density and temperature and from metal temperature
- Heat produced by fission and by radioactive decay processes
- Heat deposition in metal and coolant
- Neutron cross-section perturbations as largely arbitrary functions of position and time
- Thermal-hydraulic core boundary conditions as functions of time

MEKIN represents the core geometry in a three-dimensional X-Y-Z cartesian coordinate system. Every reactor region is the same size. In the axial dimension the reactor core is bounded by horizontal planes. In the horizontal plane the outer reactor boundary can be irregular. Either full-core, half-core, or quarter-core symmetry can be treated.

Associated with each neutronically homogeneous region is a set of correlated neutron cross sections in either one or two neutron energy groups. These data include the coefficients required to evaluate neutron cross sections as functions of coolant temperature and density, metal temperature, xenon concentration, and control absorber.

A neutronic fine-mesh geometry is superimposed on the reactor geometry. The axial dimension is subdivided uniformly into axial mesh intervals, each containing a centered mesh point. There are one or more axial mesh points associated with each reactor region. In the horizontal plane each reactor region is subdivided into one or more square-mesh intervals of equal area, each containing a centered mesh point. Thus, in the three-dimensional geometry there are an equal integral number of neutronic mesh points contained within each reactor region. Values of neutron flux, delayed neutron precursor concentration, and equilibrium xenon concentration are computed and stored for each mesh point. Each thermal-hydraulic region corresponds to one reactor region.

Reflector regions can be excluded from the thermal-hydraulic geometry but included in the neutronic geometry. One additional plane of unheated thermal-hydraulic regions can be included, each above and/or below the axial extent of the active reactor core. Average values of coolant density, coolant temperature, and fuel temperature are computed and stored for each thermal-hydraulic region.

Thermal-hydraulic models are based on a modified form of COBRA III (*2*) and impose conservation of mass, energy, and momentum in each thermal-hydraulic region. Although only the reactor core is modeled, the thermal-hydraulic boundary conditions can be expressed as time-dependent conditions in order to match conditions computed by state-of-the-art plant dynamics codes. Cross flow and turbulent mixing between the adjacent assemblies in pressurized water reactors are modeled.

The neutronic model is transient finite difference neutron diffusion theory. Either one or two neutron energy groups and up to six delayed neutron families are treated. General homogeneous boundary conditions (including zero flux, zero net current, and generalized albedo conditions) can be specified. At the user's option, the neutronic model can be "switched" from a full three-dimensional model to either a one-dimensional axial synthesis model or a point kinetic model during the course of a transient calculation.

Although the code is now available, only limited testing and confirmation have been carried out. Further work in increasing confidence in the use of the code and in reducing computation times is planned. *Project Manager: Burt Zolotar*

Status of New Projects Related to the Nuclear Cross-Section Data Base Development

Four new projects have been initiated in an attempt to improve the performance of the Evaluated Nuclear Data File (ENDF/B-IV).

Recent studies (*3*, *4*) of the apparent discrepancy between measured capture rates in ^{238}U and those calculated by using ENDF/B-IV data have indicated significant uncertainties in the lowest few resonances of ^{238}U and a large sensitivity in the calculations to the representation of the cross sections in the wings of resonances.

In an attempt to resolve this discrepancy, the Rensselaer Polytechnic Institute has been awarded a one-year project (RP511) for the measurement of the ^{238}U capture cross section by the self-indication method. This method is particularly sensitive to the shape of cross sections in the valleys between resonances. The experiment will emphasize the energy range from 0.5 ev to about 100 ev and will be carried out at a range of temperatures from 77°K (liquid nitrogen) to over 1000°K to provide a test for Doppler broadening calculations.

A program for improving the thermal cross sections of the ENDF/B-IV fissile materials has been continued with a seven-month project (RP512) awarded to Battelle, Pacific Northwest Laboratories (BNWL). Under this project, BNWL will extend a nonlinear data fitting technique (*5*) developed under a previous contract to include simultaneous fitting of scattering and total cross sections in addition to the present capability of fitting capture, fission, and eta data. The technique will then be applied to the evaluation of ^{235}U thermal cross sections.

The objective of the two projects described above is the preparation of ENDF/B-IV–based multigroup libraries for the ARMP cell analysis codes EPRI–CELL and EPRI–CPM. Under an eighteen-month project (RP452), the Los Alamos Scientific Laboratory (LASL) will process selected ENDF/B-IV materials into a "supergroup" form that will consist of about 200 groups extending from thermal energies up to 20 Mev. A second-stage computer code will be used for collapsing this intermediate supergroup library into the form required by most common cell analysis codes. A second six-month project with LASL (RP453) will result in an ENDF/B-IV–based fission product library for use in the burnup and depletion code CINDER. *Project Manager: Odelli Ozer*

FUELS, WASTE, AND ENVIRONMENT

Documentation of LWR Operating Data

The purpose of this project is to provide operating reactor reference data for qualification of calculation tools. EPRI's interest in these data is in testing the codes referred to as the

Advanced Recycle Methodology Package (ARMP) being developed under RP118. It is expected, however, that the sets of reference data will be useful for qualification of other reactor core performance analysis and fuel management tools.

The objective of the work is to obtain and document a complete set of reactor operating data from prototypical BWRs and PWRs extending through three cycles of operation. Acquisition and documentation of the data base will be accomplished by using formats and procedures consistent with applicable standards and the intended end use of benchmark calculations.

At the present time three contractor organizations are gathering information on four operating plants. Nuclear Associates International is working with Northern States Power to document information on the Monticello plant and with Florida Power and Light on the Turkey Point #3 plant.

A team at Georgia Institute of Technology is collaborating with Virginia Electric and Power on Surry #1, and S. M. Stoller Corp. is working with Northeast Utilities Service on Millstone #1.

It is expected that design and operating data sufficient for the construction of neutronic and thermal-hydraulic models of these four reactors will be available for methods verification work early in 1976. As part of RP497, an equivalent documentation effort for Quad Cities #1 is to be undertaken by General Electric in cooperation with Commonwealth Edison. Future work under this project will provide similar information for selected newer and larger reactor plants. *Project Manager: Robert N. Whitesel*

DEVELOPING APPLICATIONS AND TECHNOLOGY

LMFBR Systems Analysis Code Development

Under RP352, Cornell University will develop an LMFBR systems analysis code. This code, consisting of nuclear, thermal, and hydraulic models, is required to analyze operational and off-normal transients in LMFBR. The code will include models of the core, primary and secondary control, and protective systems. Transients within the above categories will be investigated until steady state is achieved, controlled reactor shutdown occurs, or core geometry begins to be altered. Using the developed code, existing reference designs will be evaluated.

This project will provide the electric power industry with a specialized capability for the analysis of plant transients. The code will be useful to both EPRI and the industry in a variety of ways, including development of general design criteria for LMFBRs, development of technical specifications, and trade-off studies. *Program Manager: A. Gopalakrishnan*

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4. S. Pearlstein, ed. "Seminar on ^{238}U Resonance Capture." BNL-NCS-50451 (ENDF-217), March 1975.

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Correction

In last month's issue, misprints appeared in the equations defining the parabolic rate constants for the total reacted zirconium in the summary of the Zircaloy-steam oxidation kinetics project (RP249). The corrected equations are:

WPI	$K_p = 2.96 \times 10^5 \exp(-33{,}200/RT)$
Klepfer	$K_p = 3.58 \times 10^5 \exp(-33{,}500/RT)$
Baker and Just	$K_p = 3.36 \times 10^7 \exp(-45{,}500/RT)$

Here, K_p is the parabolic reaction rate constant in units of $(mg/cm^2)^2/sec$, R is the gas constant in units of cal/(mole deg), and T is the absolute temperature (K). The conclusions regarding the relative conservatism of the three equations are correct as originally stated.

Transmission and Distribution Division

John J. Dougherty, Director

EPRI's first JOURNAL included a brief overview of the T&D Division's six research programs. The following is a more detailed description of two programs: AC Substations and Distribution. The next issue of the JOURNAL will review the AC Overhead Lines Program and the System Planning, Security, and Control Program.

AC SUBSTATIONS PROGRAM

Experts who project electric energy requirements tell us that the demand for electric energy will continue to increase and the sources of generation will continue to shift. Rapid and significant advances in transmission substation equipment are essential if large generating complexes are to deliver energy to load centers in a manner that is environmentally and economically acceptable. We are confident that environmentally improved substation equipment and high benefit-to-cost ratios can be achieved.

The ac portion of the Substations Program is primarily equipment-oriented and comprises projects grouped into eight subprogram areas. Efforts underway to achieve improved equipment reliability and increased efficiency at lower cost in each of these areas are discussed below. *Program Manager: Narain Hingorani*

Research Related to Environmental Effects

Although the majority of the projects in the environmental effects subprogram are related to transmission, two interesting efforts are in the substation area. A contract with Allis-Chalmers involves the development of tuned enclosure panels for power transformers to effect a reduction in noise levels at lower costs than can be achieved with present techniques.

In another project, Ohio State University is developing modeling techniques to permit accurate electric field predictions on proposed EHV and UHV substation designs. Several methods of field measurement are also being evaluated within this project. *Project Managers: Allan Johnson, Edward Norton*

Insulators and Bushings

The higher voltages and larger currents now necessary in many substation applications make it more difficult and costly to support conductors and to transmit currents through grounded barriers. Work in the substation insulator and bushing subprogram is underway to keep pace with other equipment developments and requirements.

Perhaps the most exciting possibility in this area is the use of polymer-impregnated concrete instead of porcelain. Low-porosity concrete is being developed that is inherently stronger and has greater dielectric strength than porcelain. Polymer impregnation increases mechanical strength and prevents moisture absorption. In addition to lower cost, production of polymer-impregnated concrete insulators will consume much less energy than that required to manufacture porcelain. This project is being conducted by the Westinghouse Research Laboratories.

To develop high-current, high-voltage bushings, the epoxy casting techniques developed by the Westinghouse Power Circuit Breaker Division are being combined with heat pipe technology. The heat pipe not only improves the temperature gradients in an operating bushing but also helps dispose of the exothermic energy generated by the curing epoxy. Application of heat pipe technology within the conductor stem is a simple, low-cost, and reliable addition to the bushing and is especially suitable where hot spots inside a bushing tend to be the limiting point of the overall equipment.

Other projects to apply advanced organic insulating materials and develop high-capacity gas-insulated bushings are planned. *Project Managers: Edward Norton, E. Robert Perry*

Switchgear

The highest priority in the switchgear subprogram has been given to the development of fault current limiters, which was described in some detail in the February issue of the EPRI JOURNAL.

Another important switchgear project is the development of a 120,000-A, 145-kv, single-pressure SF_6 interrupter underway at the Westinghouse Power Circuit Breaker Division. Basic investigations are in progress on two concepts: a liquid SF_6 interrupter and a high-pressure puffer. This project is expected to result in a design for a high-performance power circuit breaker that will be reasonable in cost.

The other high-potential interrupting medium is vacuum. This important technology is being extended in a project recently started by General Electric Corporate Research and Development. The objective is to achieve a significant advance in a high-voltage, high-current interrupter bottle that can be economically applied to transmission circuit breakers. The physical principle that will be exploited is the maintenance of a diffuse arc in the vacuum bottle. This could greatly reduce contact erosion and enhance voltage- and current-interrupting ability.

The complementary capabilities of vacuum and SF_6 suggest the possibility of developing a combination, or hybrid, circuit breaker. A project with I-T-E Imperial Corp. involves an attempt to take advantage of the synergistic effect of the two types of interrupters in series.

Basic arc studies and development of disconnects, load-break devices, capacitor/reactor switches, and grounding equipment are also being pursued and will warrant EPRI support in the future. In addition, EPRI is participating in an ERDA-funded project at I-T-E Imperial to develop a synchronous circuit breaker. *Project Managers: Narain Hingorani, Allan Johnson, Richard Kennon Consultant: Glen Bates*

Transformers

The power transformer is a key component in the electric power system and deserves increased attention in view of rising material costs, environmental concerns, and the demand for ever-larger ratings.

The life of a transformer and the impact of overload on its life are matters of considerable debate and concern to utilities. It is important to obtain reliable loading-life relationships for power transformers and to ascertain the causes of failures. Preliminary R&D in these areas will be conducted on selected subassemblies of windings that are representative of power transformers.

The key to power transformer load management is an accurate and prompt indication of actual hot spot temperatures. For this reason a project is being sponsored at Nucleonic Data Systems Corp. to develop a hot spot detector that can be located at the hottest area and transmit temperature data to a tank-wall-mounted receiver. This device will give the operating utility reliable, real-time information of actual hot spot temperatures and the utility will then be able to make the best use of transformer loading capability. Other hot spot detectors may also be developed.

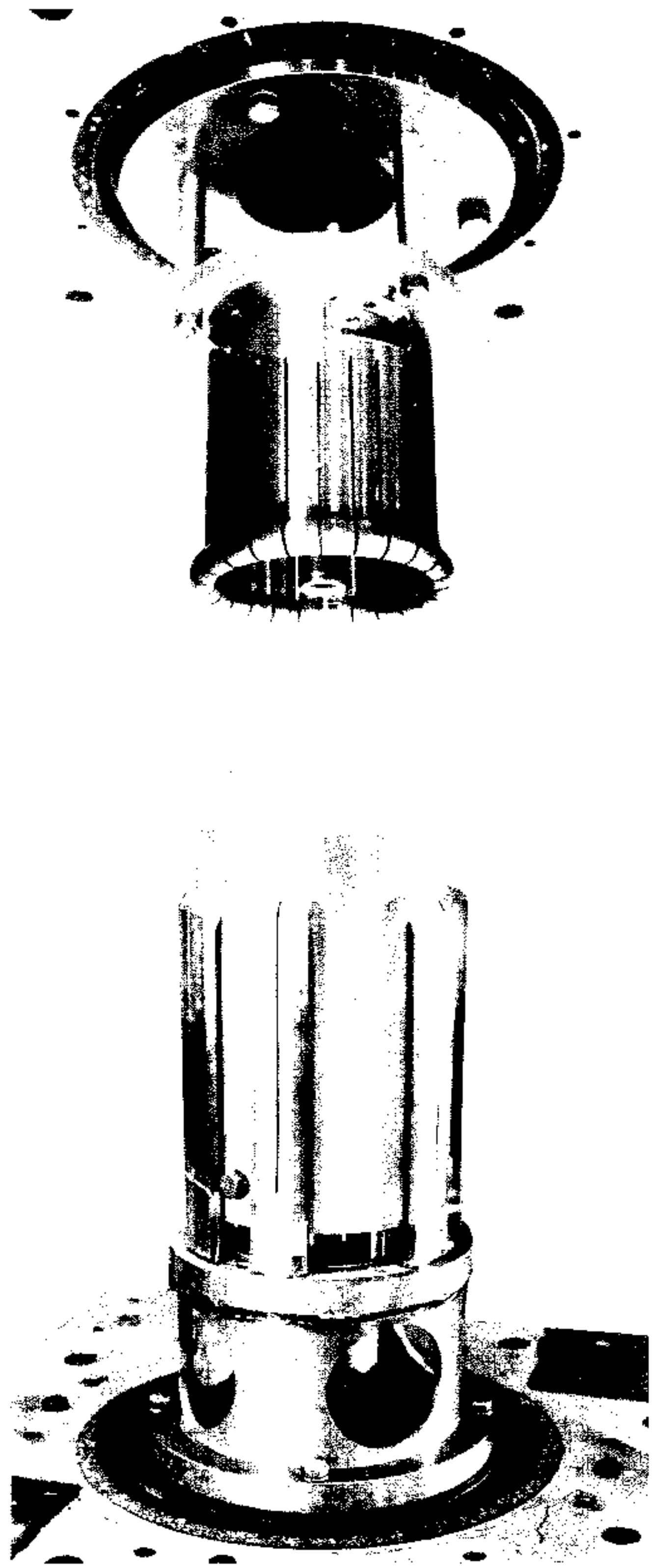


Figure 1 Single pressure SF_6 interrupter parts that will be tested at the Westinghouse High Power Laboratory.

A transformer oil study is underway with three manufacturers and will continue into 1978. Its objective is to maintain the supply of suitable insulating oils despite declining reserves of naphthenic-based oil.

Prediction of power transformer failures could have a considerable effect on service continuity and repair costs. In a project with Westinghouse and Nucleonic Data Systems, an improved incipient fault detector for transformers is being developed.

New transformer concepts involving gas insulation, vapor cooling, improved core steels, and greatly reduced weights will deserve attention as funds become available. *Project Managers: Walter Johnson, Edward Norton*

Surge Arresters

It now appears that it will be possible to limit the voltage on substation equipment to a predetermined value only slightly above the maximum operating voltage. The protective level may be low enough to eliminate overvoltage insulation as a determinant of equipment size or cost. This will be achieved through the development of the nonlinear volt-ampere characteristics of metal oxides. EPRI-funded projects with McGraw-Edison Co. and Westinghouse will explore this potential. EPRI is also participating in an ERDA-funded project at The Ohio Brass Co. that includes the development of an SF_6 surge arrester gap. *Project Managers: Narain Hingorani, Richard Kennon*

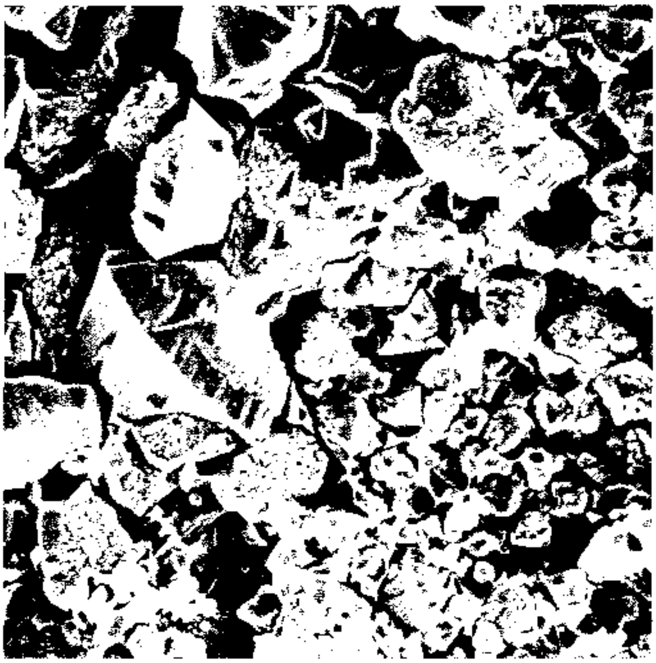
CTs, PTs, and Relays

The increased power capacity of transmission systems will impose new requirements on the instrumentation, protection, and control equipment in substations. The accuracy, dependability, speed of response, and other performance requirements of the equipment will increase. False operation of the control equipment or incorrect operator actions can cause serious disturbances of power systems. The R&D effort for substation protection equipment will be directed toward highly dependable, accurate, and fast digital relays, combined with matching, economical transducers and communication systems. These subsystems must be integrated with the conventional substation instrumentation and control functions, such as annunciators, sequential event recorders, fault recorders, operator controls, and display systems.

An EHV CCVT calibration project about to be completed was briefly discussed in the February JOURNAL.

An EHV current transformer using an optical data path is being developed by Westinghouse, which will also undertake a real-time, high-frequency transient analysis project on an operating utility's transmission system. The data gained from this investigation will greatly benefit the relay projects described below.

Figure 2 Scanning electron microscope view (× 400) of zinc oxide nonlinear resistor for surge arresters recorded at the Thomas A. Edison Laboratory of McGraw-Edison Co.



Ultra-high-speed relays for line protection and current limiter control are presently needed in a few locations, and the need is certain to be greater in the 1980s. Research is planned to develop line fault and noise models to support development of algorithms and prototype relay designs.

The use of digital techniques for protective relaying should lead to more accurate, adaptable (either self-adjustable or adjusted by dispatcher/operator command), self-checking, low-maintenance solid state relays. *Project Managers: Walter Johnson, Stig Nilsson*

Capacitors and VAR Compensation

Within the subprogram area dealing with power capacitors, major emphasis is being placed on the application of static-controlled VAR sources for transmission applications. A pilot project is underway that includes installation of a static VAR control package on the Minnesota Power & Light Co. system. Emphasis will be on quantifying the potential benefits to a transmission system and on developing control schemes that provide incremental VARs to meet varying system conditions. Possible benefits in tempering system transient swings will also be evaluated.

As funds become available, research on power capacitors will seek development of advanced capacitor units sized for application in compact ac and dc transmission terminals. This work will also evaluate external versus internal fusing and improved capacitor protection schemes. Highly nonlinear resistors will be studied for overvoltage protection and the damping of subsynchronous oscillations on series-compensated lines. *Project Manager: Richard Kennon*

Gas-Insulated Substations

Gas-insulated substations (GIS) include a wide range of devices and systems. Projects within the switchgear subprogram, transformer subprogram, and CT, PT, and relays subprogram will produce benefits for GIS equipment. In addition, any major breakthroughs that occur in the EPRI Underground Transmission Program or the ERDA Surge Arrester Program would provide direct spin-off benefits.

In an effort to carefully consider the additional projects that might be justified, industry needs are being evaluated. Through questionnaires to the utilities and meetings with the manufacturers, key areas of concern are being explored. Preliminary results indicate major utility interest in assembling design data in a single reference source and in developing techniques to permit lower-cost equipment.

An area of great potential benefit in underground transmission, switchgear, and GIS equipment is the development of a gas or gas mixture with properties superior to those of SF_6. In this area ERDA is undertaking a basic research effort, and EPRI is considering supplementing this with in-depth consideration of applications for gases that show great promise. *Project Managers: Walter Johnson, Edward Norton*

DISTRIBUTION PROGRAM

Demands for ever-increasing power capacity, utilization of higher distribution voltages, and needs for more automation and greater control sophistication indicate that future distribution systems will be more complex than those today. Increasing restraints in the areas of reliability, environment, esthetics, and safety are additional challenges to overcome. Innovative and ambitious distribution research programs are necessary to meet the growing demands of these systems and to resolve the economical and technical challenges that are involved.

The program is divided into seven subprograms, each of which deals with a distinct part of the distribution system. *Program Manager: Richard Steiner*

Distribution Planning Tools

Distribution systems have grown almost unchecked until recently. Planning the size and nature of tomorrow's distribution systems has challenged the abilities of even the most experienced forecasters.

Once a comprehensive data base is developed, computers can be used to model future growth and predict system needs. And these needs will determine the demands on the transmission system that feeds the distribution system. The efficient use of scarce capital for major investments in transmission and distribution equipment is the ultimate benefit.

The initial objective of the distribution planning subprogram, therefore, is to develop a data base from which improved load-forecasting tools will evolve. These tools must be sensitive to rapid changes in the economy that affect demand for power. Statistical approaches eventually can be applied as an additional tool to assess the risk of capital involved in overexpansion versus the loss of reliability resulting from excessive demands placed on a fully loaded system.

After a properly structured data file has been established, other tools will be developed, for example, the evaluation of losses on distribution systems and the effect of automated protection plans. *Project Manager: William Shula*

Subsystem Analysis

This subprogram is directed toward three major areas: fault management, distribution automation, and the dynamic behavior of distribution systems under transient conditions.

Electric utilities have realized the economies of scale that result from larger generators, higher transmission voltages, and larger substation transformers. But as a result, fault duties have risen dramatically, and the cost of the equipment that can withstand increased fault duty has also risen. Three projects to develop current-limiting devices are currently funded in this subprogram: one involves improved design of current-limiting fuses, and the others, the design and development of ac current-limiting devices.

Although the potential benefits of automated distribution systems have long been recognized by utility engineers, the reality of automation has been stymied by the lack of economical and reliable communication systems. Nevertheless, recent emphasis on energy conservation and improvement-of-load factor has accelerated the interest in distribution automation. In the next four-year period EPRI and ERDA will jointly fund projects that will explore the feasibility of distribution automation. Large-scale field demonstrations of communication systems on actual distribution systems will be performed throughout the country. Statistics on data transmission reliability and accuracy will be demonstrated through the performance of such functions as automatic and time-of-day meter reading, simulated load control, capacitor bank switching, and distribution sectionalizing.

The last section of this subprogram's activities concerns the dynamic behavior of distribution systems. Although the dynamic behavior of transmission systems has been explored for many years, is well documented, and the research has reached a high degree of sophistication, only limited knowledge is available on distribution systems. Technological advances in materials and equipment, rising costs of all components, and the desire to maintain a high degree of service reliability dictate that distribution system electrical behavior be better understood. Projects are planned that will monitor fault currents to verify calculated values. The generation, propagation, and attenuation of surges and transients will also be studied so that adequate protective devices can be developed. Studies are planned that will define sources of harmonic generation on distribution systems, and the effect of these harmonics on distribution components will be evaluated. *Project Managers: Frank Sherman, Richard Kennon*

Overhead Distribution Lines

For the foreseeable future, overhead line construction will continue to make up a large portion of most utility distribution systems. There are diverse overhead system problems that require near-term research and solution. Improved lightning protection, better storm-proofing, increased wood pole longevity, and controlled tree growth are major objectives of this subprogram. Five research projects are planned for these problem areas in the 1976–1979 time period.

In addition, two projects now underway are designed to investigate suitable substitutes for present poles. The cost of wood poles has more than doubled in the past three years. As a result, the economics of using such substitutes as foamed glass or particle wood now appears promising. *Project Manager: Robert Tackaberry*

Underground Distribution Lines

Underground distribution systems are now commonplace and have reached some degree of maturity. Therefore, the R&D course for underground lines becomes somewhat clearer than in the past. The short-term objectives of our underground subprogram are threefold: reduction of corrosion; definition of thermal limitations of present cable insulation systems and development of improved systems; development of equipment and work methods that are compatible with the total underground distribution concept.

Corrosion of copper concentric neutrals has been reported in several areas of the country. Deterioration of these neutrals has serious implications for the economics and protection of underground distribution systems. Two projects are underway to develop viable methods to mitigate corrosion, and additional projects are anticipated because solutions to corrosion problems will require long-term R&D commitments.

Thermal characteristics of solid dielectric cable insulations operating in an earth environment are not well understood. Material and equipment costs and other economic considerations have forced increased loading on all underground components. Because overloading of cables can lead to serious consequences, substantial R&D effort is necessary. A project is underway to study the thermal capabilities of cables. A second project is planned to improve insulation quality so that cable can be operated under higher voltage stress. Additional projects will involve cable shielding, cable accessories, and perhaps a follow-on project on insulation treeing. One project will involve using a laser for the in-process detection of voids in solid dielectric cables. This technique could lead to substantial improvements in the reliability of cable insulations and a lowering of cable repair or replacement costs.

It appears that the ultimate objective of most utilities is to attain a totally submersible underground distribution system. Substantial emphasis will therefore be placed on the development of economical and reliable transformers, fuses, sectionalizing devices, capacitors, and other equipment that will operate satisfactorily in a subsurface environment. Nine specific projects are currently planned for the development of such equipment in the 1976–1979 period.

Labor costs associated with underground systems are still high in relation to overhead systems. Considerable research effort, therefore, will be devoted to the development of installation equipment, tools, and work methods that can lower the labor component of these costs. At present, three specific projects are planned. *Project Manager: William Shula*

Distribution Substations

The heart of the distribution substation, and its most costly component, is the power transformer. As a result, several projects are planned to find ways of prolonging transformer life and reducing losses. The dynamic response of the transformer windings during through-fault conditions will also be studied. Projects are underway to define the correlation between transformer loading, aging, and basic insulation level. Other projects of interest are the development of alternative, safe, dielectric fluids; the building of a prototype power transformer that may be operated at extremely high temperatures for higher load capability; and the development of a transformer hot spot detector. Another project will investigate methods to prolong oil life and find substitutes for the present naphthenic-based insulating oils.

Other studies to be carried out under this subprogram will involve the compatibility of the distribution substation with its environment, which often is a residential neighborhood. Developments are needed to lower noise levels, improve appearance, and reduce the size of distribution substations. *Project Manager: Edward Norton*

R&D Testing and Consultation

Many distribution engineers believe that independent distribution testing and product evaluation facilities are needed. At present, however, there is no facility in the U.S. specifically designed to test distribution system concepts or distribution products.

Two distinct types of facilities are needed: a product evaluation laboratory (in which extensive testing and evaluation would be conducted on design concepts and products) and a distribution system demonstration facility. This facility would have one or more three-phase feeders, single-phase laterals, underground and overhead construction, and actual or simulated loads. It would be available for testing, proving, and demonstrating new equipment, control schemes, design philosophy, instrumentation, operating techniques, and other features important to real-system operation, design, and construction.

An industry distribution test facility would not only ensure uniformity of test procedures and unbiased test results but would also reduce overall industry costs for system and product development testing. *Project Manager: Richard Steiner*

Metering

Meter maintenance and meter-reading costs continue to impose a growing burden on utilities while rapid advances in technology and development of solid state devices into microprocessors have reduced the cost of these devices. Therefore, research will be initiated to develop metering devices that incorporate solid state technology. This new generation of meters must be compatible with future communication systems so that meters can be read via novel communication channels. A need also exists for the development of remote registers that can be added to existing meters, permitting meter reading at a distant location. Three specific projects of this type are planned during the 1976–1979 period. *Project Manager: William Shula*

Energy Systems, Environment, and Conservation Division

René Malès, Director

BENEFICIAL USES OF WASTE PRODUCTS

The first half of the 1970s witnessed a marked change in our perception of constraints on meeting world demands for food, energy, and raw materials. The last half may see even more changes. Sound plans for developing future technology require that these be taken into account. Among the possibilities is the constructive use of by-products from energy production processes; several of these are shown in Table 1, together with conventional and potential uses. Focusing on waste heat alone (Table 2) reveals five areas of application that might be developed. Among them, aquaculture has so far had the most attention and is now a subject of research definition by EPRI's Environmental Assessment Department.

The attempt to use reject heat aquaculture systems (RHAS) with operating power stations has not appeared to be economically attractive. If such a system were to be designed along with the planning for a new power plant, it might be possible to achieve an attractive balance of economic, environmental, and societal conditions.

Apparent economic advantages of an integrated system to an electric utility are reduced costs for the construction and operation of cooling systems and the income to be derived from the sale of heated effluent to the aquaculture system. Disincentives include possible interference with operations (e.g., not being able to use a preferred biocide treatment) and reduced efficiency (e.g., occasional steam bleed-off to maintain optimum effluent temperatures for the aquaculture system).

To the aquaculture system operator, the major economic incentive is low-cost heat. Disincentives include the possibility of power plant outage at single-unit sites during colder months, which could result in mortality or in increased costs for an alternative heat supply.

To be viable, aquaculture systems must provide products at projected competitive costs. A near-term market is high-value food species, such as oysters and lobsters. Longer-term, an increasing worldwide need for protein could alter the situation by the mid-1980s. Low-cost protein can be produced via an algae-animal chain, a promising outlook if a high-conversion efficiency animal can be used.

This positive use of reject heat may create other impacts, in at least some locations. RHAS may significantly affect the environment through evaporative losses, makeup water requirements, effects on groundwater, or unfavorable conditions for indigenous life forms.

A first step will be to develop a general model to aid in examining the possibilities for the use of RHAS. The model will have to provide for different climates, locations, salinity, temperature regimes, and regional resources and requirements, as well as for the species to be cultured. For freshwater systems, currently possible species include catfish, crayfish, tilapia, and freshwater prawns. For saltwater and estuarine systems, they include American lobster, shrimp, oysters, salmon, and clams.

The model must also consider the thermal and water quality requirements for power plant effluent entering the system. For example, leached metals and residuals from chlorine or other antibiofouling agents could seriously affect the aquaculture possibilities. Similarly, the quality of effluent water leaving RHAS must be considered—high nitrogen or phosphorus residuals could make the effluent unacceptable for entry into natural water systems.

EPRI is supporting research in the factors described above in order to define criteria for and limitations to the development of RHAS. If there appears to be a successful route, coordination and integration with the R&D programs of individual utilities and the federal government will be the next step. *Project Manager: Harry Kornberg*

BIOLOGICAL EFFECTS OF HIGH-VOLTAGE ELECTRIC FIELDS

To make better use of limited transmission corridors, to reduce energy line loss, and to provide electric service as economically as possible, electric utilities have increased overhead transmission voltages. Maximum ac transmission voltage in the U.S. is nominally 765 kv, and voltages above 1000 kv are

Table 1
ENERGY BY-PRODUCTS AND POSSIBLE USES

By-Product	*Use*
Fly ash	Concrete Mineral resource Soil conditioning
Low-grade heat	Agriculture Aquaculture Heat for industry Recreation Space heating
Nuclear fuel residuals	Medical radioisotopes Other useful radioactive material
Scrubber sludge	Building materials
SO_x	Sulfuric acid

Table 2
AREAS OF POTENTIAL USE FOR LOW-GRADE HEAT

Area	*Use*
Agriculture	Frost control Greenhouse heating Soil warming to extend growing season
Aquaculture	Growth rate enhancement Spawning control
Industry	Chemical processing Integrated energy systems Sewage treatment
Recreation	Bathing beaches Warm-water fisheries
Space heating	Development of new cities Retrofitting existing developments

being explored. To determine if there are any possible biological effects that might be produced by high-voltage electric fields, EPRI contracted with IIT Research Institute to review the worldwide literature and ongoing research and to identify useful areas for additional effort (*1, 2*).

Although the bulk of evidence (principally for line frequencies of 45–75 Hz) reveals no observable biological effects under EHV lines, further research is needed to determine whether or not there could be subtle effects. For this reason and on the recommendation emerging from a consultants' workshop, a research program was developed that identified and set priorities for 23 specific research tasks. Following that program plan, the Environmental Assessment Department is now supporting or considering projects in five major categories:

- Exposure and physiological monitoring of individual subjects
- Chronic exposure of large animals
- Ecological effects
- Epidemiological studies on linemen
- Effects on implanted pacemakers

The summary of findings in the IITRI reports are discussed in the following paragraphs. The report covered approximately 800 papers on research in the U.S. and several other countries.

To assess the effects of high-voltage fields, it is not sufficient to specify the voltage of the line. The voltage gradient (kilovolts per meter) must also be specified. For example, an isolated conductor carrying 500 kv 10 feet above the ground generates the same voltage gradient at ground level as a similar conductor carrying about 1000 kv at an elevation of 20 feet. Beneath a typical 765-kv line the maximum vertical field 4 feet above the ground is about 9 kv/m. The corresponding magnetic field generated by 2000 amperes flowing through the line is 0.31 G (gauss, a measure of magnetic flux). Maximum figures are not characteristic; random measurements made under lines yield lower numbers.

One way to gain perspective on these figures is to compare gradients from power lines with natural and other man-made electric fields. Beneath thunderclouds, 3 kv/m and more have been measured. Dust storms in northern West Africa can reverse the earth's 0.13 kv/m field (caused by the ionosphere) and produce fields up to 1.5 kv/m. The earth's natural magnetic field is about 0.5 G.

Examples of man-made ac electric fields are those from electric blankets (0.24 kv/m), broilers (0.13 kv/m), stereos (0.09 kv/m), and electric ranges (0.004 kv/m)—all at distances of about 1 foot. Soldering guns and hair dryers can generate 10–24 G in their vicinity, and a can opener, a kitchen range, or an electric shaver, 5–10 G. Thus, people were exposed to natural electric and magnetic fields before electricity was harnessed and have been exposed to appliance fields for over half a century.

A recent report from the USSR stated that occupationally exposed linemen experienced nausea, lassitude, loss of appetite, and reduced sexual drive. Subsequently, the USSR promulgated time limits for exposure to electric fields greater than 5 kv/m. A report from Spain described a similar syndrome among switchyard workers transferred to a new 500-kv station. These reports intensified interest in whether higher voltage gradients under some transmission lines and in switchyards could cause adverse biological effects.

Investigations in Western Europe and in the U.S. produced different findings. No effects were found from research studies on linemen, switchyard workers, farmers who worked in fields crossed by high-voltage lines, and volunteers in human experiments. An example is reported in a recent German study in which volunteers had been exposed to 50-Hz electric fields of up to 20 kv/m for up to 3 hours without observable effects. An epidemiological study from France reported no differences in the health of two groups of people, one group living within 25 meters of a 200-400-kv line and the other living at a minimum distance of 120 meters. The highest gradient to which human subjects were intentionally exposed in a psychological experiment was 100 kv/m. Although a few subjects exhibited discomfort, the study reported no effect of the field on test performance.

At gradients about 100 times those found in the field, unfavorable biological effects have been induced in mice: paralysis at 1000 kv/m, hair erection and discomfort at 700 kv/m, and (in contrast with the reports on Soviet linemen) arousal at 200 kv/m. Mice exposed to 160 kv/m for 1500 hours showed no effect when compared with control subjects. One study reported that offspring from exposed animals showed a slightly lower growth rate than those from the control group, but the authors suggested the difference may have been due to a variation in maintenance conditions.

Results of numerous other laboratory studies and field observations of grazing animals, honeybees, and birds have indicated no undesirable effects. Electric current densities and amplitudes considerably greater than those experienced by workers beneath EHV lines have been beneficially used for bone growth stimulation, electrosleep, and electroanesthesia —all apparently without long-term biological effects. Further extensive research sponsored by the U.S. Navy revealed no significant biological effects of high magnetic fluxes (over 30 times that of the earth) and associated voltage gradients (up to 0.1 kv/m).

Despite the abundant evidence that there are no significant effects, EPRI has established a major research program in this area in an attempt to reconcile the conflicts in reported research results. *Project Manager: Harry Kornberg*

References

1. EPRI 381-1 *Biological Effects of High-Voltage Electric Fields: State-of-the-Art Review and Program Plan,* Final Report. Prepared by IIT Research Institute, November 1975.

2. EPRI 381-1B *Bibliography on Biological Effects of Electric Fields,* Final Report. Prepared by IIT Research Institute, November 1975.

NATURAL RESOURCES

Because uranium is expected to play a major role in the nation's future energy supply, an early priority of the Energy Supply Program was basic research on uranium resources and supplies. Even before contract research could get underway, the staff prepared a study of uranium resources for EPRI President Chauncey Starr in connection with his responsibilities as a member of the Nuclear Working Group of the President's Energy R&D Advisory Council. The EPRI study report, *Uranium Resources to Meet Long-Term Uranium Requirements* (SR-5), contains estimates of resources and requirements in probability terms.

Although at the time the estimates contained in SR-5 were considerably higher than those of ERDA, the study revealed a substantial probability that before the end of the century the nation would be short of uranium to supply the lifetime requirements of reactors. Based on the report, Dr. Starr was asked to submit recommendations for improving estimates of uranium resources. These recommendations, drafted by the staff of the Energy Supply Program, were adopted by the President's Energy R&D Advisory Council.

Contract research on uranium has been designed to expand the data available and improve the methodology of forecasting resources and supplies. Two contracts were awarded originally. One inquired into the nature and quality of the uranium reserve and the resource data maintained by ERDA and by the uranium mining industry. The companion study focused on uranium exploration in an effort to throw more light on the process of uranium discovery, as well as to indicate the current and prospective status of discovery techniques. Both these studies are nearly complete and reports should be published shortly.

In the mineral industries, costs are complex. Some cost elements are related to the geographic, geologic, and chemical nature of ore deposits, and others to such factors as economic rents and inflation. In addition to costs, there is the question of price, which is affected by the basic balance between supply and demand. Rapid shifts in perceived supply or demand can produce large deviations in the cost-price relationships. To better understand these factors, a study of cost and price formation in the uranium and coal industries was initiated. This study should identify the mechanism by which costs and prices evolve and thus significantly help in forecasting possible future prices.

A major uncertainty about industry's ability to discover uranium deposits at rates to meet potential needs is caused by the status of uranium exploration technology. At the present time drilling, guided by conventional geologic factors, is the major tool for discovering deeper deposits. An attractive alternative is locating likely uranium areas by finding evidence of relative abundance of uranium decay products. Theoretically, the ratio of helium isotopes could provide a clue to uranium deposits, and research is being initiated to evaluate that theory. If successful, a method would be provided that could significantly improve uranium supply estimates.

The search for uranium is leading to deeper, lower-grade deposits and to possible deposits in other than the conventional sandstone formations, yet there is no systematic body of knowledge dealing with the costs of uranium from these sources. Research has been initiated to evaluate the cost of conventional mining and milling deeper, lower-grade deposits and to evaluate a new technology for uranium recovery: solution mining. This research will also include a preliminary evaluation of the prospective costs of recovering uranium from nonsandstone deposits. *Program Manager: Milton F. Searl*

ENERGY PRODUCTION AND CONVERSION

An analysis of future relationships between coal prices and coal production levels is the ultimate goal of the Energy Supply Program's ongoing and planned work in coal supply economics. Future price-supply relationships will be determined primarily by:

□ Factors that bear directly on the cost of mining, preparing, transporting, and utilizing coal. In addition to direct production costs, these factors include a reasonable return on investment and normal business taxes (such as federal income taxes).

□ Other less direct costs, such as reserve acquisition costs, royalties, and higher-than-normal profits that are combined with the more direct costs to determine the market price. These less direct costs are influenced by such items as prices of competing energy sources, government policies, industry organization, and pricing conventions.

Under an EPRI contract with Pennsylvania State University, Dr. Richard L. Gordon, professor of mineral economics, is surveying and evaluating recent coal supply studies and meeting with people currently conducting such studies (RP335-1). His analyses indicate that much work remains to be done before there will exist an adequate understanding of future price-production relationships. EPRI published 18 of Dr. Gordon's reviews last summer in the Key Phase Report, *Economic Analysis of Coal Supply: An Assessment of Existing Studies* (EPRI 335). Under the same title, a second volume. Final Report Vol. 1, has just been published.

In the area of direct production costs, the major effort has been the preparation of coal production cost models for underground and surface mines (RP435-1). Models being developed by NUS Corp. will permit the calculation of minimum acceptable selling prices for coal, given such information as seam characteristics, mine type, mining system, and financial requirements. These models will be used in estimating the cost of mining U.S. coal resources.

A requirement for the use of all models is adequate input data. To ensure completeness, consistency, and economy of manipulation, EPRI is considering financing work at Oak Ridge National Laboratory to develop an efficient methodology for incorporating data on coal resources in a computer-managed file.

An understanding of the economic process of price formation in the U.S. coal industry is being developed by Charles River Associates (RP666, which also deals with uranium pricing). This study should help the Energy Supply Program forecast possible future coal prices.

Bulk coal transportation is a vital element in the coal supply equation, and we are attempting to gain a better understanding of this element. An analysis of the capacity of existing bulk transportation systems to carry increased volumes of coal is soon to be completed by Manalytics, Inc. (RP437). The study will help identify potential transportation bottlenecks by characterizing interregional transportation networks as a series of links between coal-producing states and FPC power supply areas.

In the area of data development, work is underway to make the coal data of FPC Form 423, Monthly Report of Cost and Quantity of Fuels for Steam Electric Plants, more readily available to researchers. For example, data on new contracts have been put on a separate tape and EPRI plans to make this (and two printed sortings of it) available in the near future. *Project Manager: Thomas E. Browne*

At the Institute

MALES NAMED DIRECTOR OF ESEC DIVISION

René H. Malès, on loan from Commonwealth Edison Company of Chicago, has been named director of the Energy Systems, Environment, and Conservation Division.

Malès succeeds Sam H. Schurr, who is returning as a senior fellow to Resources for the Future, Inc., Washington, D.C., after two years with EPRI. Schurr will continue with EPRI as a consultant.

A graduate of Ripon College, Malès studied mathematics at the University of Chicago before obtaining an MBA from Northwestern University. He joined Commonwealth Edison in 1956, was named director of economic research in 1965, became assistant to the vice president of division operations in 1970, and was promoted to manager of general service in 1973.

Malès is a member of EPRI's Supply, Demand, and Conservation Advisory Task Force and Edison Electric Institute's Energy Analysis Division Advisory Committee. In 1974 he was a member of the U.S. Commerce Department's Technical Advisory Committee on Project Independence. In addition, Malès has served on the National Petroleum Council's Subcommittee on Electric Utilities, the Federal Power Commission's National Power Survey committees, and on the National Academy of Engineering's Committee on Power Plant Siting.

Greenberger New Energy Systems Modeling Manager

Martin Greenberger, on a two-year leave from Johns Hopkins University where he is professor of mathematical sciences and senior research associate of the Center for Metropolitan Planning and Research, recently became manager of the Energy Systems Modeling Program. At Johns Hopkins, Greenberger did research in and taught economics, modeling, policy analysis, and computer science. His interests are in decision problems relating to technology and public policy.

Before his association with Johns Hopkins, Greenberger was on the faculty of the Alfred P. Sloan School of Management at the Massachusetts Institute of Technology. It was there that he helped establish Project MAC, a large, interdisciplinary research effort that pioneered in the development and use of on-line interactive computer time-sharing systems.

Prior to joining the MIT faculty, Greenberger formed and managed an IBM research group at MIT that assisted the Harvard Smithsonian Astrophysical Observatory in tracking the first Soviet and U.S. satellites.

Greenberger holds AB, AM, and PhD degrees from Harvard University.

Board Approves $50 Million in New Energy Research

The EPRI Board of Directors, meeting in Atlanta on February 5, approved $50 million in electric energy research for 44 new projects and increased authorizations for 26 ongoing projects.

A major authorization was an additional $8.4 million for a coal gasification combined-cycle test facility at the Powerton generating station of Commonwealth Edison Co.

The development of processes whereby various types of coal can be used more extensively, while meeting environmental and economic standards, is the objective of much of the approved research. Also authorized were projects for developing technology to control air pollution from fossil-fuel-fired power plants.

In addition, $18.5 million was approved for projects to develop advanced types of energy systems. Approval was given to begin the design and construction of the Battery Energy Storage Test (BEST) Facility. Scheduled for completion by the end of this decade, the facility will be constructed at a substation of the New Jersey Public Service Gas and Electric Co.

Other actions included the appointment to the EPRI Advisory Council of James McGirr Kelly, commissioner of the Pennsylvania Public Utility Commission and president of the National Association of Regulatory Utility Commissioners. Appointed to the EPRI Research Advisory Committee were Everett D. Smith, group vice president of construction, production, and engineering for Dayton Power and Light Co., and D. E. Simmons, vice president of environmental and interutility affairs for Houston Lighting & Power Co.

Kelly

Smith

Simmons

In nuclear power research and development, a number of projects to increase reactor reliability, operation, and performance were approved.

The Board also approved a plan that would provide up to $11 million for the development and demonstration of a 4.8-Mw fuel cell module. EPRI's funding of the program is contingent upon the commitment of $34 million in support from ERDA and other sources.

Two key transmission and distribution projects were authorized. One will determine the practicality of trapping magnetic fields in a superconducting cylinder as an alternative to today's costly process of winding electromagnetic coils. The second project will test the possibility of using a laser for locating microscopic impurities during the manufacture of underground cables rather than after installation.

Other significant expenditures will be directed to forecasting cost and availability of coal resources and of producing uranium.

The total value of the 664 research projects now under management or in contract negotiation, including joint funding, is $497 million. EPRI's share of this amount is $354 million.

Hodel Named to EPRI Board

Don Hodel, administrator of the Bonneville Power Administration (BPA), has been designated by Secretary of the Interior Thomas S. Kleppe as the U.S. Department of the Interior (DOI) representative on the EPRI Board of Directors. Hodel succeeds Jack W. Carlson, who resigned the office of assistant secretary for energy and minerals at DOI.

Hodel was named administrator of BPA in December 1972. In this capacity, he is responsible for directing the activities of the second largest power-marketing organization and the largest high-voltage transmission system in the free world. BPA constructs, maintains, and operates more than 12,000 miles of high-voltage transmission lines throughout Oregon, Washington, Idaho, and western Montana.

Hodel was previously deputy administrator of BPA. Prior to that he was active in both corporate and private law practices in Portland, Oregon. He has a BA in government from Harvard and a JD from the University of Oregon.

EPRI Representative Delivers Data from Halden Project

"The Halden Reactor Project, without a doubt, has the most advanced capability for on-line measurement of fuel rod behavior in the world."

Garry Thomas (left), EPRI's representative on Norway's Halden Reactor Project, and Floyd Gelhaus, manager, EPRI's Fault Analysis and Modeling Program, discuss experimental data on fuel rod behavior, which will be analyzed to help improve the performance and reliability of water-cooled reactors.

That is the reaction of Garry Thomas, EPRI's "man in Norway," after one year of work in the Norwegian Institutt for Atomenergi's international experimental facility for improvement of performance and reliability of water-cooled reactors. Thomas spent a week at EPRI headquarters in mid-January to discuss the analysis of recent experimental data on fuel rod behavior.

"At Halden we are monitoring fuel rods to see how they react to changes in core power. Fuel rod 'reacting' normally means changing dimensions, which affects the fuel's lifetime," Thomas stated.

"Garry brought us a lot of *whats*," explained Floyd Gelhaus, manager of the Fault Analysis and Modeling Program. "Now we have to analyze them to get the *hows* and *whys*. Halden is providing us with good data on fuel rod behavior under varying operating conditions. It gives us the ability to specify, control, and record the power environment much more closely than in any power reactor. We can also follow the elastic and plastic changes (distortions) while the rod is on power. By analyzing these data, we should come up with insights on combinations of fuel rod design and reactor operations that will increase reactor availability significantly and produce more power from a given amount of fuel.

"I am particularly impressed with the spirit of cooperation and experimental objectivity that results from the totally impartial international staff at the Halden Project," Thomas said. "Ours is mainly a data-gathering function. Detailed analysis of that data is done elsewhere—in our case, at Palo Alto." Thomas will be in Norway another six months before returning to EPRI.

Gelhaus was asked when tangible results could be expected from the Halden Project and when the results would impact the nuclear power industry.

"That's hard to put a finger on," said Gelhaus, "when we are dealing with such an intangible product as understanding." Ed Zebroski, director of the Systems and Materials Department, said, "I believe the most tangible near-term results will be the ability to calibrate our several fuel models, which now give widely different results for some calculations. This should help both in fuel procurement and in licensing. Past insights from the Halden program have already filtered into the industry through some of the vendors. In a similar fashion, our current insights or analyses can influence future fuel specifications and plant operation procedures."

EPRI was first accepted for full participation in the Halden Project in January 1974, and a three-year renewal agreement was signed in November 1975. Data and analyses from EPRI's participation will be published in EPRI reports.

Coal Supply Economics Workshop

Examining ways to improve research and data methods for predicting future costs and prices for North American coal was the objective of a Tampa, Florida, workshop sponsored by EPRI's Energy Supply Program on December 9 and 10.

Participating in the workshop were approximately 30 specialists from research organizations, private industry, and government agencies that are involved in various aspects of coal supply analysis. The participants were divided into six working groups: resources and reserves, mining and transportation costs, new utilization technology, government policies, coal industry structure, and interrelationships between these areas.

"Recommendations made by the participants will aid EPRI and others in their coal supply analysis methods," says Thomas Browne, workshop chairman and project manager in the Energy Supply Program. "Proceedings from this workshop should be available soon." EPRI currently has three projects on different aspects of coal economics. The projects, funded at $340,000, will provide a review of existing coal supply studies, a mining production cost model, and an analysis of the relationship between coal costs and prices since 1945.

Balzhiser Calls for Balanced Approach to Air Quality Management

An urgent call to identify "the real threats to public health and the environment before mandating costly emission control systems for fossil-fuel-fired electric power plants" was recently voiced by Richard E. Balzhiser, director of the Fossil Fuel and Advanced Systems Division.

In emphasizing the need for a balanced approach to air quality management, he said that "tall stacks with supplemental controls are by far the most cost-effective air pollution control technology available."

Keynoting the 12th Air Pollution and Industrial Hygiene Conference on Air Quality Management in the Electric Power Industry at the University of Texas campus on January 28, Balzhiser cautioned that "it is worthwhile to question common premises to be sure that we are pursuing real problems and not their symptoms.

"Once the constituents that must be controlled are identified, the massive engineering and construction effort to implement controls must take place. As much as $13 billion could be required to meet 1980 sulfur oxide control requirements with technology that may not guarantee protection of public health."

Balzhiser referred to authoritative predictions that electricity production must double every 10–15 years over the balance of this century if essential energy and economic demands are to be satisfied. "Analysis called for an electric generation mix in the year 2000, equally divided between coal and nuclear sources. This leads to a utility coal demand four to six times greater than current consumption and to a uranium requirement six to eight times greater than today's proven reserves.

"The impact on public health and the environment of a sixfold increase in coal-fired generation could be substantial. And, although protection of public health should be paramount, there will be only so much low-sulfur coal available; so much scrubber production capability; only limited clean, coal-derived fuels in this century; and so much money to pay for all this. Our resources must be properly managed to meet this challenge.

"It is vital to have a clear concept of what is being controlled and why. We do not have, even now, a definitive understanding of what constituents of stack emissions are hazards to human health and the environment. . . . The mechanisms of pollutant formation and transformation must be understood before optimal control technology can be devised and perfected."

Balzhiser concluded his remarks by calling for cooperation between "government and industry in the identification of real health problems from power plant emissions and the short-term applications of all available technologies to deal with present air pollution problems. This can buy us time to develop optimal technology to realize long-term improvements in air quality."

New Research Findings on Lead-Acid Batteries Presented at Workshop

The first national program undertaken in the U.S. to examine the application of lead-acid batteries in electric utility systems has been partially completed, and the results were presented at a November 18–19 workshop held at EPRI.

The research program, now in its second phase, is being funded under separate contracts by EPRI, ERDA (through Argonne National Laboratory), and the International Lead Zinc Research Organization (ILZRO). These groups cosponsored the workshop, which was attended by representatives from the largest U.S. battery manufacturing companies and 13 electric utilities. Major objectives of the workshop were to present the first-phase findings and to incorporate the reactions of the participants into the second phase.

"The first part of the study was basically a design-and-cost analysis of lead-acid batteries for utility application," says Jim Birk, a project manager in EPRI's Electrochemical Energy Conversion and Storage Program. "The lead-acid battery has been around for over 100 years, so we already know quite a bit about it. What we're trying to do is to take this knowledge and develop a lead-acid battery design to meet the specific needs of the electric utility industry."

Based on the results of this first phase, lead-acid batteries appear to be expensive for utility application. Utility participants at the workshop indicated that the 10-hour lead-acid battery, emphasized in the first phase of the study, is too expensive ($1000/kw) for load-leveling application. On the other hand, there was interest in the 3- and 5-hour lead-acid batteries, whose costs are projected to be about $425/kw and $600/kw, respectively.

A committee of EPRI, ERDA, and ILZRO representatives will continue to oversee the program. In the second phase, program contractors ESB, Inc., Gould, Inc., and C&D Batteries (a division of Eltra Company) will be interfacing with Bechtel Corp. in order to determine costs for 3- and 5-hour lead-acid battery plants. The study will comprise efforts between the architectural and engineering firms and the battery companies to develop system designs that will result in the lowest overall costs for electricity. In addition, under an ERDA contract, Public Service Electric and Gas Co., New Jersey, will undertake system expansion studies to determine affordable costs for load-leveling batteries. At the conclusion of the second phase, ERDA and EPRI will assess the prospects of lead-acid batteries for utility application and decide whether a demonstration plant is warranted.

Transmission Line Problems Subject of Monterey Workshop

Discussing ways to improve the costly, labor-intensive process of building and operating power transmission lines was the topic of a two-day seminar recently held in Monterey, California. Over 50 contractor, consultant, supplier, and utility representatives attended.

Following an introductory period to explain the goals of EPRI and the organization of the Transmission and Distribution Division, the group was divided into five task forces to address the following problems: wire stringing and directly related equipment; towers and footings; maintenance; design, as it relates to construction and maintenance; and right-of-way and clearing.

The task force on towers and footings at a recent transmission line seminar held in Monterey, California, defines research needs.

The task forces identified broad problem areas that would be likely to benefit from a centralized research effort. These areas were then discussed to further define specific transmission line research opportunities, especially work methods, new components, and better design data for operation and construction. The group also discussed the possibility of demonstrating various material and equipment concepts under EPRI sponsorship.

EPRI technical staff members are presently considering recommendations for sponsorship of more than 10 specific research projects identified by the task forces.

A brief summary of the views expressed and the conclusions reached during the seminar is available from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303.

Compressed Air a Likely Option for Peaking Requirements

"The development of compressed-air energy storage plants may help reduce utility dependence on oil, increase the overall efficiency of baseload power plants, and in certain cases, defer the need for new baseload plants," states Joseph Pepper, project manager, Thermal-Mechanical Energy Conversion and Storage Program.

Gas turbines, which are often relied on to meet peak power demands, use premium fuels, such as oil. As Pepper explains, "Off-peak baseload power that uses cheaper fuels, such as coal or uranium, could compress air for underground storage. During peak periods this high-pressure air would be injected along with oil into a gas turbine, thus eliminating the need for premium fuel to compress the air.

"In a gas turbine using premium fuel, the heat rate is around 12,000 Btu per kwh as compared with a compressed-air storage plant that would use around 4500 Btu of premium fuel per kwh plus 8000 Btu of cheaper baseload fuel per kwh."

To ensure that utility interests will be met in developing energy storage, a two-day workshop was held last December in Airlie House, Virginia, with representatives from 15 U.S. electric utilities and other interested domestic and foreign groups. This international workshop was cosponsored by EPRI and ERDA.

At the workshop, findings from a recently concluded EPRI–ERDA study on assessing energy storage technology for utility applications were presented. A key conclusion of the study was that compressed air and underground pumped hydro are technically and economically feasible storage systems and could be available for commercial use by 1985.

In certain areas of the U.S., conventional aboveground pumped hydro is being used, although it is geographically restricted. States Pepper, "Because it has fewer geographic restrictions and environmental implications than conventional pumped hydro, compressed air is a likely candidate for meeting utility energy storage needs."

A project now under consideration for funding by EPRI and ERDA would entail the conceptual design of a compressed-air storage demonstration plant. The Federal Republic of Germany leads in the development of this technology and is constructing the world's first compressed-air storage system, with operation slated for 1977.

According to EPRI officials, three major reasons for current interest in storage are scarcity of oil and natural gas, growing environmental concerns, and high cost of capital for new plant construction.

Workshop Serves as First Stage of R&D Planning for Load Forecasting

"Forecasting peak kilowatt demand and the relationship of the peak to other time periods are as important to researchers and utility planners as determining what the total kilowatthours will be," states James W. Boyd, project manager in the Energy Demand and Conservation Program.

To assist EPRI in formulating a research program on methodologies for forecasting time-of-day and seasonal loads, a group of representatives from the electric utility industry, government, and the academic community met last December for a two-day workshop in Pacific Grove, California.

"The EPRI program will develop methods for forecasting kilowatt demands for planning long-term capacity requirements and helping to identify research and development priorities," says Boyd. "Since the energy crisis, most energy forecasting research has concentrated on annual kilowatt demand and the forecasting of hourly demand has received less attention than it probably deserves."

Researchers need to accurately forecast instantaneous demands so they can establish priorities for research and development programs; evaluate the cost-effectiveness of such experimental programs as time-of-day pricing; ascertain the impact of new commercial technologies (for example, electric cars); and assist utilities in their planning.

Patent Application by Loaned Employee

A patent for a new type of NO_x control oil burner has been applied for by EPRI. The design is the work of Donald Anson, a loaned employee from Great Britain's Central Electricity Generating Board (CEGB), who is serving as a staff engineer in EPRI's Fossil Fuel Department.

A problem in utility operations concerns the protection of off-load burners. While at CEGB, Anson initiated work on this problem and developed a new burner design. Anson's work at EPRI carried his development further, and his newest design provides for the control of NO_x pollutants by recirculation of flue gas.

LMFBR Utility Committee Members Named

Twelve executives from the utility industry have agreed to serve on the LMFBR Utility Committee that will overview the recently initiated, 30-month, joint EPRI–ERDA program for the design of a near-commercial fast breeder reactor.

In a letter welcoming the members to the committee, EPRI President Chauncey Starr said, "It is my strong conviction that the project getting underway represents a necessary and urgent precursor to the fast breeder option, which could be an absolute necessity if this country is to continue to improve or even to maintain its standard of living in the future."

A major purpose of the LMFBR Utility Committee is to ensure the program's responsiveness to utility needs. The specific objectives of the committee are to:

- Provide utility perceptions to the program as it develops
- Ensure that the criteria and design approaches incorporate the requirements and objectives of the utility industry
- Advise on policy relationships between all involved parties—EPRI–ERDA, vendors, architect-engineer teams, NRC, and the utilities
- Consider the longer-term implications of LMFBR developments as they take place, together with the associated needs for further action
- Assist in conveying to the utility industry the results of this program

The twelve new members of the LMFBR Utility Committee are:

Chairman: J. L. Everett, III, President
Philadelphia Electric Co.

Vice Chairman: Herman Dieckamp
President
General Public Utilities Service Corp.

Thomas G. Ayers
President/Chairman of the Board
Commonwealth Edison Co. of Chicago

E. K. Davis, General Manager
Sacramento Municipal Utility District

William R. Gould, Senior Vice President
Southern California Edison Co.

Leonard Koch, Manager
Nuclear Project, Illinois Power Co.

Walter McCarthy, Jr.
Executive Vice President, Operations
The Detroit Edison Co.

John J. Mattimoe
Assistant General Manager
and Chief Engineer
Sacramento Municipal Utility District

G. W. Nichols, President
New England Electric System

Ruble Thomas, Vice President
Southern Services, Inc.

A. J. Wagner, Chairman of the Board
Tennessee Valley Authority

Richard F. Walker
Vice President, Engineering and Planning
Public Service Co. of Colorado

Project Highlights

EPRI Negotiates 20 Contracts

The Electric Power Research Institute announced the signing of 20 new research contracts in January. Funding for the 620 research projects either under management or in contract negotiation (including cosponsored funding) amounts to $415 million, with EPRI contributing $303 million as its share of the total. Descriptions of a representative sampling of new projects follow. A complete list is on page 53.

EPRI–NBS Acoustic Emission Study

Early detection of potential structural degradation is important for safe and reliable operation of nuclear power plants. Toward this end, EPRI and the National Bureau of Standards (NBS) are cofunding a $1 million project to develop the theoretical basis, measurement techniques, and calibration procedures required to evaluate the technical feasibility of a system of defect detection called acoustic emission.

Acoustic emissions are analogous to pressure waves released during an earthquake in that they are waves created by deformation, or dynamic movement, within a structure. These waves travel through the structure and are detected by sensors attached to its surface. Just as in geophysical studies, the amplitude and time of arrival of acoustic emission signals are used to estimate the magnitude and location of the deformation.

Acoustic emission shows great potential for detecting the onset of structural failures under load conditions and for monitoring known cracks in pressure boundary systems. This potential has been limited by a lack of information relating particular acoustic emissions to specific kinds of defects.

Completion of this three-year project will provide the electric power industry with the capability of calibrating an acoustic emission transducer to national standards and the ability to relate acoustic emission signals to their structural significance. The ultimate goal of this work is a system for continuous monitoring of the integrity of pressurized components.

Criteria for Technology

What is meant by *technically ready*? What is a *demonstrated* technology? What are the parameters for judging the status of new technologies?

As many as 15 or 20 variables may be necessary to accurately characterize the state of development of a new technology, according to Milton Searl, manager of EPRI's Energy Supply Program, when announcing a contract awarded to the University of Denver.

The $70,000 study will involve a survey of existing and proposed methods used by industry, government, and the educational community to determine the stages of a technology's development. "The results of the project will give EPRI management a consistent way of characterizing the development stages of diverse technologies," said Searl. "Wise allocation of research and development resources depends heavily on the ability to assess the status of developing technologies."

He further remarked that an important distinction exists between technical readiness and commercial acceptance. "While a technology may be mature and attractive in a technical sense, it may be rejected or it may never even enter the marketplace for a host of reasons, such as lack of public acceptance, cost, or government policy. On the other hand, a technology may be commercially accepted or advocated and then proven technically unready.

"We often read in the press about a new technology that someone has demonstrated," concluded Searl, "but such questions as, 'Was the demonstration long enough to encounter normal operating problems?' or 'Has reliability been demonstrated?' need to be answered before sound research recommendations can be made.

Solar Research Underway at 53 Utilities

SUMMARY OF UTILITY SOLAR RESEARCH

Project Area	*Companies*	*Active Projects*	*Planned Projects*
Solar energy availability and weather data	37	36	9
Solar demonstration projects	33	42	26
Solar system performance and impact on utility operations	28	29	9
Other solar-related activities	30	40	29

Fifty-three electric utilities are either sponsoring or planning 220 individual solar research projects, according to a recent survey by EPRI. The utilities identified in the survey are conducting this research in addition to their support of EPRI's Solar Energy Program.

"By no means was the study designed to be an exhaustive survey of what the utilities are doing in solar research," emphasizes John Cummings, project manager for solar heating and cooling studies. "It represents the first step in developing an industry data base in anticipation of more solar research by electric power companies."

The survey was initiated for three reasons: to assist EPRI in developing its solar program; to inform electric utilities of solar research being conducted by other utilities; and to develop a list of utilities interested in receiving EPRI solar energy research results.

The utility projects were categorized into four groups: solar energy availability and weather data, technology demonstration, solar system performance and its impact on electric utility operations, and other related solar activities.

Although most of the activity was found to be in the eastern and southwestern states, a number of projects are being planned in other areas of the country.

In projects with direct solar energy emphasis, the primary areas of interest are in solar energy availability and weather data and in technology demonstration. These areas account for 113 of the 220 projects. Since the initial phase of the EPRI solar heating and cooling program is also geared to these two areas, these findings are especially significant.

In the areas of solar energy availability and weather data, 51% of utility activity is related to monitoring weather data, 40% to monitoring solar energy availability, and 9% to other activities.

In solar demonstration projects, 27% of utility activity is related to solar water heating, 36% to solar space heating, 16% to solar air conditioning, 13% to solar system component testing and evaluation, and 8% to other activities.

"The survey showed the growing interest of the electric utilities in examining the potential impact of solar energy for heating and cooling applications," commented Cummings.

More detailed information on the solar survey results can be obtained from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303.

Development of Zinc-Chlorine Battery

A zinc-chlorine battery that may help electric utilities meet peak power demands is the subject of a $1 million, one-year project, jointly funded by EPRI and Energy Development Associates (EDA), Madison Heights, Michigan. This new effort is the second phase of an anticipated multiyear development program.

The project calls for the fabrication and testing of two full-scale cells rated at 2 kwh each. The first-phase test results on a 1-kwh cell justified proceeding to the next stage, according to Jim Birk, EPRI project manager for advanced battery systems.

Birk believes the zinc-chlorine battery may be the first advanced battery that utilities can use commercially for load leveling. It is hoped that eventually a zinc-chlorine battery of megawatt size can be developed and used to store electric energy in power systems. Power companies presently meet their peak electricity demands mainly by gas turbines or by pumped hydro stations.

In the current project, researchers will make economic and technical comparisons of the two different chlorine electrode materials contained in each cell. (One cell uses graphite, and the other, ruthenized titanium.) On completion of these comparisons, a submodule of 10 full-scale cells will be constructed and tested.

"We hope that the first megawatt-size zinc-chlorine battery system can be built by 1979," remarked Birk, who stated that such a system could conceivably be the first one tested in the Battery Energy Storage Test (BEST) Facility.

Public Service Electric and Gas Co., New Jersey, will be the prime contractor for the BEST Facility.

BEST Facility Contractor Named

Experience in demonstrating advanced energy technologies, lack of suitable sites for conventional pumped hydro, and recent assessments of advanced energy storage concepts were factors that contributed to the decision of Public Service Electric and Gas Co. (PSE&G), New Jersey, to submit a proposal for appointment as prime contractor of the Battery Energy Storage Test (BEST) Facility, according to PSE&G's Peter A. Lewis.

PSE&G will now work with cosponsors EPRI and ERDA to move the program into its preliminary engineering phase. The BEST Facility is being built at a utility substation so that battery system performance can be tested and characterized on complete systems in a user environment, following extensive battery system component testing by the developers.

The facility, scheduled for completion by 1979, will include a control room, general shop area, interface equipment, station and battery auxiliary equipment, and test areas called bays. Initially, only one of the three planned test bays will be fully implemented, at an estimated cost of $6.4 million. When the remaining two bays are opened, the cost will be approximately $3.3 million.

The facility will play a key role in the development and evaluation of advanced battery systems that could meet the electric utilities' need for more energy storage. Batteries would store energy when demand is low for use during periods when demand is high. By using the stored energy to help meet peak demand, less efficient, more costly generation could be eliminated. Thus, peaking or load-leveling operation with storage batteries could help utilities make optimum use of their installed generating capacity and reduce their total system generating costs.

Stated Lewis, "For PSE&G, a functional demonstration of the capabilities of advanced energy storage concepts is a necessity—not an academic exercise. Through this demonstration, potential purchasers of large batteries will gain confidence in the technology and thereby accept this method of energy storage at the earliest possible time."

Laser Fusion as Potential Power Source?

What would a laser fusion reactor look like? When might it be used in power plants? What other applications could it have in addition to producing electricity? What would it cost?

Answers to these questions will be sought in a new phase of an ongoing fusion program sponsored by EPRI at the University of Wisconsin.

During this $1 million, 30-month project phase, researchers will define reactor fuel and design requirements for a type of fusion system that uses the intense heat of a laser to ignite reactor fuel. The resulting energy could then be used in a number of utility applications—for example, making steam in a turbine generator.

"As the process is now envisioned," explains Noel Amherd, EPRI project manager for fusion research, "small pellets of fuel, perhaps a deuterium and tritium combination, would be blasted with the laser beam's light. Some of the laser energy would be transferred to the pellet's interior with a subsequent release of thermonuclear energy."

To achieve a fusion reaction, hydrogen fuel (of which deuterium and tritium are isotopes) needs to be burned at temperatures hotter than the sun's interior. The problems are how to contain the hot fuel and how to sustain the reaction to the break-even point—the point where the amount of energy produced by the fusion reaction equals the amount of energy used to start it.

Two methods are being developed to confine the burning fuel. One employs magnetic fields; the other uses the pellet's inertia to hold it together during burning. Laser fusion is a form of inertial confinement. The University of Wisconsin has examined magnetic confinement for EPRI in previous projects, and consequently, one of the major outputs of this new work will be a comparison of reactor designs employing these two confinement techniques.

EPRI and the University of Wisconsin will work closely with other fusion developers, especially the University of Rochester in New York, the Los Alamos Scientific Laboratory in New Mexico, and the Lawrence Livermore Laboratory in California.

New Contracts

Fossil Fuel and Advanced Systems Division

No.	Title	Duration	Funding ($000)	Contractor
RP234-3	Ultra-High-Temperature Turbine Program	2 years	3,727.0	General Electric Co.
RP528-1	Gas Turbine—Steam Boiler Repowering	1 year	175.8	Westinghouse Electric Corp.
RP556-1	Environmental Baseline Data Acquisition at Heber	13 months	140.0	San Diego Gas & Electric Co.
RP638-1	Standard Time-Temperature Parameter for the Correlation and Extrapolation of Elevated Temperature Creep and Rupture Data	1 year	27.5	Metal Properties Council
RP645-2	Studies of Advanced Fueled Fusion Reactors Suitable for Direct Energy Conversion	2 years	220.0	Lawrence Livermore Laboratory
RP713-1	Investigation of Mechanisms of Reactions Involving Oxygen-Containing Compounds in Coal Hydrogenation	2 years	339.5	Gulf Research & Development Co.
RP714-1	Hydrogen Production from Liquefaction Residues	8 months	300.0	Texaco Research & Development Co.
RP725-1	Advanced Electrostatic Precipitator Pilot Plant—Prephase I	5 months	225.0	Air Pollution Systems, Inc.

Transmission and Distribution Division

No.	Title	Duration	Funding ($000)	Contractor
RP7850-1	High-Temperature Gas-Insulated Systems	2 years	455.5	I-T-E Imperial Corp.

Nuclear Power Division

No.	Title	Duration	Funding ($000)	Contractor
RP497-1	Quad Cities-1 Plutonium Recycle Nuclear and Fuel Performance Measurements	2 years	678.0	General Electric Co.
RP609-1	Acoustic Techniques for Measuring Stress Regions in Materials	3 years	402.0	Stanford University
RP624-1	Steam Plant Surface Condenser Leakage Study	1 year	217.1	Bechtel Corp.
RP685-1	Extensions of the Finite Element Method	1 year	120.0	Marc Analysis Research Corp.
RP693-2	Hydrodynamic Analyses of Pressure Suppression Systems	6 months	50.0	Jaycor, Inc.
RP696-1	Fracture Toughness Statistical Analysis	1 year	95.0	Fracture Control Corp.

Energy Systems, Environment, and Conservation Division

No.	Title	Duration	Funding ($000)	Contractor
RP263-2	Energy Analysis with a Linear Economic Model	4 months	10.0	University of California, Berkeley
RP572-3	Determination of the Feasibility of Ozone Formation in Power Plant Plumes	6 months	55.1	University of Washington
RP652-1	A Physical Flow Model for Assessing the Feasibility of Alternative Energy System Scenarios	1 year	35.0	Stanford University
RP652-2	A Physical Flow Model for Assessing the Feasibility of Alternative Energy System Scenarios	10 months	15.0	University of Santa Clara
RP760-1	Appraisal of Net Energy Analysis	10 months	29.8	Criterion Analysis, Inc.

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

New Publications

Fossil Fuel and Advanced Systems

EPRI 110 ATMOSPHERIC POLLUTION ASPECTS OF MAGNETOHYDRODYNAMIC POWER PLANTS *Final Report*

This report describes research conducted by the High-Temperature Gasdynamics Laboratory, Stanford University, on the economics and emissions of nitric oxide of projected magnetohydrodynamic (MHD) power plants. The research consisted of two parts: a systems study and laboratory measurements. The systems study addressed the question of capital and operating costs of a coal-burning MHD system and the possibility of controlling potentially excessive emissions of nitric oxide. Although earlier work had shown MHD to be favorable with regard to cooling water requirements and SO_2 emissions, concern had arisen over potential stack emissions of nitric oxide as a result of the high combustion temperatures of the MHD cycle. To investigate this question, the systems study required data on the rate of decomposition of nitric oxide. The rates of the dominant chemical reactions, however, had not been measured at the combustion temperatures of interest. An experimental program was undertaken to obtain these fundamental data. The results of these measurements should be of interest for conventional power plants and other combustion applications.

The systems study concluded that an MHD cycle has the potential for reduced operating costs in comparison with the conventional plant and that nitric oxide emissions could be controlled by means of two-stage combustion. The laboratory measurements provided values for the dominant rates of NO decomposition in the temperature range of interest. These rates were incorporated in the analysis of the systems study. *Contractor: Stanford University*

EPRI 233 DESIGN OF 50-MW CLOSED MHD BLOWDOWN EXPERIMENT *Final Report*

A design study that focused on the major components of a 50-Mw closed-cycle MHD blowdown experimental facility was performed in conjunction with anticipated acceleration of federally sponsored efforts in this area. The facility was designed for short-duration, steady state (blowdown) tests of a closed-cycle, nonequilibrium MHD generator to verify scaling laws and steady state operability of such generators. *Contractor: General Electric Company*

EPRI 127-2 DEVELOPMENT PROGRAM FOR SOLID ELECTROLYTE BATTERIES *Interim Report*

The annual report describes TRW's program to develop load-leveling sodium-sulfur batteries using disk electrolytes. Emphasis during the report period was on electrolyte and seals development and on initial testing of laboratory cells that reflected many of the design concepts of TRW's full-scale cell. *Contractor: TRW Systems Group*

EPRI 391-1 EVALUATION OF THE FEASIBILITY OF LOW-COST CARBON DIOXIDE REMOVAL/TRANSFER METHODS FOR FUEL CELL APPLICATION *Final Report*

The molten carbonate and alkaline electrolyte fuel cell technologies could be considerably enhanced if cost-effective means were available for removing carbon dioxide from a fuel stream or for transferring carbon dioxide from the fuel stream to the air stream. Under RP391 several techniques for removal/transfer of carbon dioxide were analyzed with respect to energy and capital cost requirements. In addition, typical fuel cell systems were evaluated in connection with the availability of waste heat and process streams that could be integrated with the carbon dioxide removal/transfer equipment.

The study concludes that the alkaline fuel cell application is better suited to carbon dioxide removal, that waste heat can provide the necessary energy, and that capital cost will depend on the system pressure. A methodology is provided that will assist fuel cell developers to analyze the energy and capital requirements of carbon dioxide transfer/removal for their specific systems. *Contractor: Giner, Inc.*

Nuclear Power

EPRI 217-1 ELASTIC-PLASTIC FRACTURE MECHANICS PARAMETERS IN FRACTURE SAFE DESIGN
Technical Report 7

The report summarizes some of the current methods for assessing the fracture toughness of materials under elastic and elastic-plastic conditions. The main parameters considered are (1) plane strain fracture toughness (K_{Ic}), (2) equivalent energy (K_{Icd}), (3) contour integral (J), and (4) crack opening displacement (COD). Gross strain crack tolerance and stress concentration methods are also discussed.

It is concluded that of these parameters the contour integral and the crack opening displacement have the most potential for future development. Although these two parameters are shown to be equivalent, at the present stage of development the COD concept has several advantages over the J concept.

The COD concept has been developed to a stage where it is possible to estimate the significance of flaws in welded structures, provided the toughness of the material and the acting stresses or strains are known. This development is described in the report and is the method used to analyze tests on model pressure vessels with 6-in-thick walls. A comparison is made with other methods, and it is concluded that although the COD analysis gives conservative estimates of the flaw size to cause failure, further work is necessary to be able to predict vessel burst conditions when failure is preceded by extensive plasticity and stable ductile tearing. A simple nomogram to determine COD levels to ensure leak-before-break conditions is also developed. *Contractor: Failure Analysis Associates*

EPRI 275-1 WATER ENTRAINMENT IN NUCLEAR REACTOR INTERCOMPARTMENTAL FLOW *Topical Report*
In this state-of-the-art survey of methods for estimating entrainment in nuclear reactor containment problems, the extensive engineering literature on two-phase flow in ducts, nozzles, and orifices is reviewed. The topics of flow patterns, holdup or slip, two-phase critical flow, and entrainment are discussed. In addition, the literature pertaining to nuclear containment calculation methods, experiments, calculation surveys, and verifications is surveyed. *Contractor: Drexel University*

EPRI 278-1 ACTIVE DIRECT MEASUREMENT OF RESIDUAL FISSILE CONTENT IN SPENT FUEL ASSEMBLIES *Final Report*
The feasibility of direct nondestructive measurements of the residual fissile content of spent LWR fuel assemblies is studied in this work. Included in the study are the definition and evaluation of a generic measuring system, along with a conceptual engineering layout of a proposed system. *Contractors: Science Applications, Inc., and Intercom Rad Tech Corp.*

EPRI 280R ANALYSIS OF GE BWR BLOWDOWN HEAT TRANSFER PROGRAM, TEST 4906 (AEC STANDARD PROBLEM FOUR) *Key Phase Report*
This is a revision of EPRI 280, which presented the prediction of Standard Problem Four. The revised report shows how the test predictions submitted for Standard Problem Four actually compare with the experimental data measured. The only difference between the two reports is the inclusion of the experimental data in the revision. Standard Problem Four is a scaled simulation of a two-loop boiling water reactor performed in the two-loop test apparatus. *Contractor: Energy Inc.*

EPRI 289-2 SINGLE-TUBE TEST FACILITY DESCRIPTION FOR PWR BLOWDOWN HEAT TRANSFER PROJECT
Technical Report 1
To improve the understanding of transient critical heat flux and post-CHF heat transfer during PWR–LOCA conditions, EPRI is currently cosponsoring an overall research project with Combustion Engineering, Inc. As part of this project, a well-instrumented, single-tube transient heat transfer loop has been built and preliminary testing has been completed. This report contains a description of the single-tube facility and its operation, as well as a brief summary of the project objectives. *Contractor: C–E Power Systems*

Transmission and Distribution

EPRI 7817-1 HIGH-AMPACITY POTHEADS *Final Report*
This report focuses on the evaluation of three patented methods for achieving higher ampacities for potheads rated 230 kv, while using one cable per phase and without any major modification in the pothead's dielectric design features or use of a larger cable conductor size. Forced oil through the conductor is the mode of cooling and is thereby the method of achieving higher ampacities. *Contractor: G&W Electric Specialty Company*

EPRI 329 ANALYSIS OF DISTRIBUTION R&D PLANNING
Final Report
This is a summary of the findings and recommendations of an industrywide survey of distribution engineering practices, current research, and anticipated institutional and technological developments that may impact distribution system analysis. The study focuses on three subject areas: system planning methods, system surveillance and control, and data file technology. *Contractor: Systems Control, Inc.*

EPRI 561 LONGITUDINAL UNBALANCED LOADS ON TRANSMISSION LINE STRUCTURES *Interim Report*
The survey results presented in this report constitute the first phase of a program for the development of design aids for the rapid determination of unbalanced longitudinal forces on both rigid and flexible transmission structures due to unbalanced ice, broken conductor or overhead ground wires, or any other abrupt discontinuity in the longitudinal conductor tensions. *Contractor: GAI Consultants, Inc.*

Energy Systems, Environment, and Conservation

EPRI 117 TRACE METALS IN URBAN AEROSOLS
Final Report
The composition of the aerosol in the New York City atmosphere was analyzed (1) to distinguish the sources of suspended and settled dusts by studying their physical and chemical properties and (2) to ascertain the extent to which trace elements present in suspended dust are absorbed by New York City residents.

The study first determined the concentration, trace element composition and particle size, and solubility of aerosols and settled dust in New York City. Samples were analyzed for the elements Pb, V, Cu, Cd, Cr, Fe, Mn, Ni, and Zn. Current dustfall levels appear to be about one hundred times lower than those reported in the 1930s.

Analyses of human tissues were undertaken to improve the knowledge of relationships between trace metal–tissue distributions and the various routes of exposure, with particular emphasis on the urban aerosol source. The tissues analyzed were the trachea and right main-stem bronchus, the right lung, pulmonary lymph nodes, blood, approximately 500g of liver, a kidney, and bone (half the bodies of three thoracic vertebrae). All specimens were obtained by a collaborating pathologist who examined the tissues for pathological changes. Multiple microscopic sections were examined and the findings recorded.

The solubility of the metals in airborne particulates has been determined and related to the distribution of these metals in the pulmonary regions of the human lung and respiratory lymph nodes. Both water and a simulated lung fluid were used to obtain an index of the availability of metal ions.

The relationships of lung and lymph node burdens to aerosol trace element concentrations of Pb, Ni, and Cr have been studied, using as a first approximation an exponential lung model based on the recommendations of the ICRP Task Group on Lung Dynamics. Excellent agreement has been found between the values predicted by the model and those actually observed in respiratory tissues. *Contractor: New York University Medical Center*

EPRI 201 INTERACTIVE EFFECTS OF SULFURIC ACID MIST AND NITROGEN DIOXIDE ON CYNOMOLGUS MONKEYS
Final Report

This report presents the findings of an investigation using 81 cynomolgus monkeys (36 males and 45 females) in 9 groups of 4 males and 5 females each. Of these, 8 groups were exposed via inhalation and under dynamic conditions to nitrogen dioxide (NO_2), sulfuric acid (H_2SO_4) mist, or to a binary combination thereof. Exposure duration was approximately 22 hours per day, 7 days a week, for 26 consecutive weeks.

The overall conclusion was that six months' exposure to the combination of 5.0 ppm of NO_2 and H_2SO_4 mist (2–4μ MMD), at a concentration of the latter (1.0 mg/m^3) which produced no lung changes discernible by light microscopy, was capable of inducing a change in the lung not seen after exposure to 5.0 ppm of NO_2 alone for the same period of time. This suggests an interaction greater than a mere additive effect, which, if borne out by further study, could have important health implications, since the above values are the current threshold limit values for NO_2 and H_2SO_4 mist. *Contractor: Hazleton Laboratories, Inc.*

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

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