Modeling System Interactions

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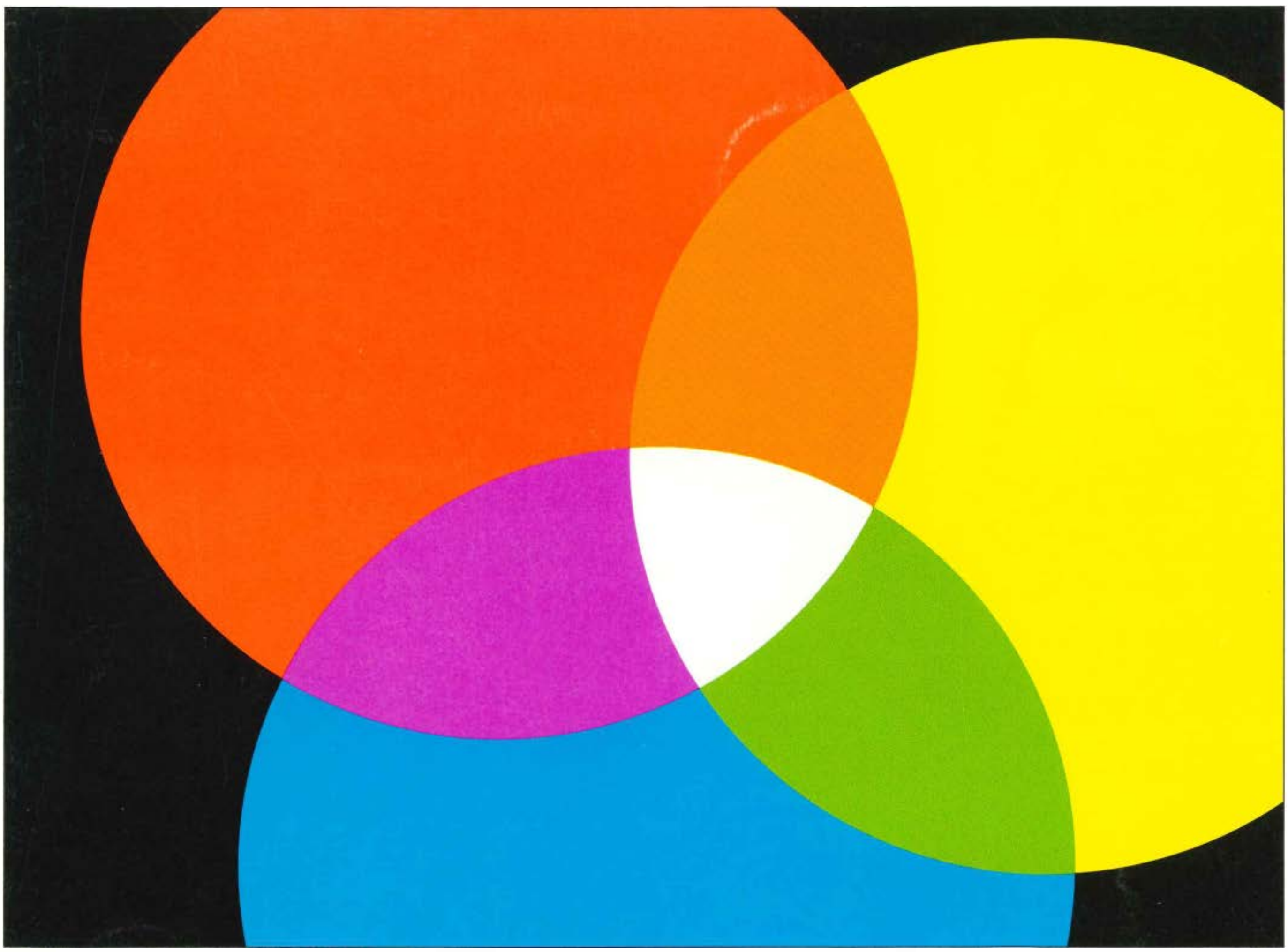

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COVER: Two of man's systems, energy and economics, overlie a third, the environment. They interact. Cause and effect. Cost and benefit. What are the factors we can control, and how? System models aid our understanding, especially when we link them to match the real world.

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A Trend to Examine

Consider the following half-dozen reports. Besides bearing on the nation's energy problems and the future of the electric power industry, the studies have something very significant in common. See if you can discern that shared element.

Electricity Forecasting and Planning, California Energy Resources Conservation and Development Commission (1976)

Economic Growth in the Future, Edison Electric Institute (1975)

A National Plan for Energy, Research, Development, and Demonstration: Creating Energy Choices for the Future, ERDA (1975)

Project Independence, FEA (1974)

A Time to Choose: America's Energy Future, a Ford Foundation study (1974)

The Limits to Growth, an MIT study sponsored by the Club of Rome (1972)

If your answer is that all these reports have evoked controversy, you are right and rate a B+, but not an A, because controversy has been the response to innumerable other studies touching (as do these) on sensitive political matters.

If you guess that the similarity is in the viewpoints of the reports, you are in error, for the outlooks run the gamut from bullish optimism to cautious concern to gloomy pessimism. Some studies are for growth, some against; one pushes for energy conservation, a second emphasizes new supply options, and a third does both. And we could add to the list a seventh study that is still under way. It is a study on nuclear and alternative energy systems by the National Resources Council.

The important element all these studies share is their use of elaborate analytic frameworks and policy evaluation tools known as systems models, the subject of the feature article which begins on page 6. These models allow for systematic exploration of the interplay between energy activities, economic forces, technological factors, and environmental constraints. Systems models carry cryptic adjectives like *econometric, input-output, programming, optimization,* and *simulation.* There are as many different methodologies used in assembling systems models as there are ways of generating electricity.

In some studies, the systems model plays a key role in the analysis. Former FEA Administrator James C. Sawhill, when issuing *Project Independence,* made clear that the models developed during the FEA study were important tools for evaluating changing world and domestic conditions and the impacts of alternative policy actions.

In other studies, the model plays a different role. Sometimes it allegedly is used to support a predetermined policy position. Indeed, the systems model can be an effective political instrument, a use about which (like industrialized society) people complain while they exploit the advantages.

When employed as a serious tool of analysis, the systems model does not answer questions so much as it helps ask the right ones. ''A model is to be used,'' according to a well-known economist, ''but not to be believed.'' Although it is applied to analysis, the systems model is itself a product of synthesis. As such, it can serve a valuable function: bringing together expertise and data from many fields.

EPRI has undertaken several projects to improve the understanding and usefulness of systems models in energy analysis, such as the Energy Modeling Forum noted on page 52. Whether viewed as a passing fashion, a political football, or a permanent fixture, the move to systems modeling is a modern trend that warrants careful study and critical examination.

Martin Greenberger

Martin Greenberger, Manager
Systems Program
Energy Analysis and Environment Division

Authors and Articles

Hardly a generation ago a model was a miniature ship and an analyst was a psychotherapist. Today, for many of us, a model is more likely to be a mathematical abstraction of relationships which simulates phenomena of the natural world or of human institutions—often a combination of the two. Such a model doesn't look like the real thing, but it acts like it.

Today's analyst is still concerned with behavior but in an expanded sphere of operation. In the world of modeling he may be an economist, a biologist, a political scientist, a geologist, a physicist, or a mathematician.

□ Jerry Karaganis is a mathematician with expertise in energy resources and systems. He may wish that he were also an economist and a biologist because his work with energy systems has revealed their links to the economy and to the environment. Karaganis explains how this is so and suggests some of its significance in "Linking the Models to Match the Systems" (page 6).

In Project Independence, Karaganis helped to pioneer an essentially new field by working to adapt a National Petroleum Council oil and gas model to the needs of FEA's benchmark effort in energy-economic modeling. That project, in Karaganis's view, was of more long-term value for the understanding it stimulated than for the findings it published.

Project Independence (and Karaganis's association with it) grew out of work by the Office of Energy Data and Analysis, Department of the Interior, where Karaganis was a mathematician performing analyses of problems involving all forms of energy. Still earlier, in 1972 and 1973, Karaganis worked in the U.S. Geological Survey. He provided technical assistance on several reports, including M. King Hubbert's *U.S. Energy Resources: A Review As of 1972,* which was prepared for energy policy studies by the Senate Committee on Interior and Insular Affairs.

Jerry Karaganis is a 1966 mathematics graduate from the University of Buffalo. He earned an MS at Western Michigan University in 1968 and has completed all but the thesis for a PhD at American University in Washington, D.C.

□ "How Can We Improve Power Plant Reliability?" asks Joseph Prestele (page 12). His topic continues to be a paramount issue facing electric utilities, and he is well qualified to judge the answers that will come from EPRI-sponsored research. With New York's Consolidated Edison since 1949, Prestele is executive assistant to the vice president, power supply. While on loan to EPRI, he is managing the Nuclear Power Division's Codes, Standards, and Reliability Program.

Prestele has been close to nuclear power development since 1956, when he became a utility consultant to General Electric Co. on land-based prototypes of U.S. Navy reactors. He was assigned to Con Edison's first Indian Point plant in 1960 and was its general superintendent from 1964 to 1969. He later managed Con Edison's Production Department and its Nuclear Power Generation Department.

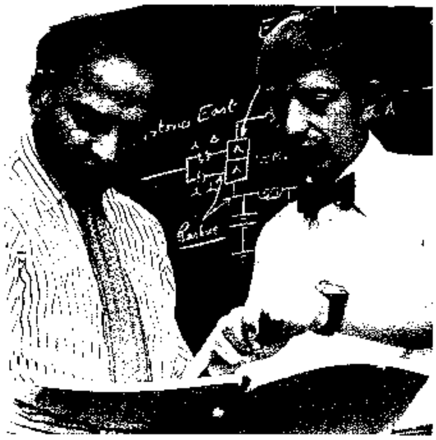
Prestele is chairman of the Standards Committee of the American Nuclear Society, a member of the Executive Standards Council of the American National Standards Institute, a technical adviser to the ANS Information Center on Nuclear Standards, and a member of Con Edison's Nuclear Facility Safety Committee.

In writing of the reliability R&D programs of two EPRI divisions, Prestele was assisted by Ed Zebroski, director of the Nuclear Systems and Materials Department, and by Donald Anson, acting manager of the Fossil Plant Performance and Reliability Program.

□ Narain Hingorani and Stig Nilsson have been working for years to develop and enlarge the role of dc in U.S. electric power transmission and distribution. Both began their careers in other countries, and both came to the United States to work on the Pacific HVDC Intertie. Now they are colleagues in the AC and DC Substations Program of EPRI's Electrical Systems Division and share the authorship of "Compacting DC Terminals" (page 18). The article reviews an EPRI

Karaganis

Prestele



Hingorani Nilsson

project for R&D, installation, and linking of two prototype dc terminals in New York City.

Before joining EPRI as a program manager two years ago, Narain Hingorani was a consultant on the staff of the Bonneville Power Administration, specializing for 6 years in system design and analysis for the dc leg of the HVDC Intertie. During 11 previous years he held research and teaching positions at three universities in England. Hingorani is an EE graduate of Baroda University in India, and he was awarded MS and PhD degrees by the University of Manchester in England.

Stig Nilsson was with Sweden's ASEA for 11 years, 7 of them devoted to control systems development and design for the HVDC Intertie. He came to the United States in 1967 as an engineer on the ASEA-General Electric joint-venture team for installing and testing the equipment.

Nilsson joined Boeing Computer Services in 1972, where he helped to develop a substation integrated control system and designed a backup control system for the HVDC Intertie. He came to EPRI a year ago.

□ When Alfred Kahn, New York's PSC chairman, was in San Francisco last summer, his days were filled with meetings: the EPRI Advisory Council, a NARUC committee, the project committee of the EPRI—EEI Rate Design Study, and—just as meticulously scheduled—an interview with JOURNAL staff writer Stan Terra. A synopsis of this conversation is on page 42, "Alfred Kahn Breaks Tradition."

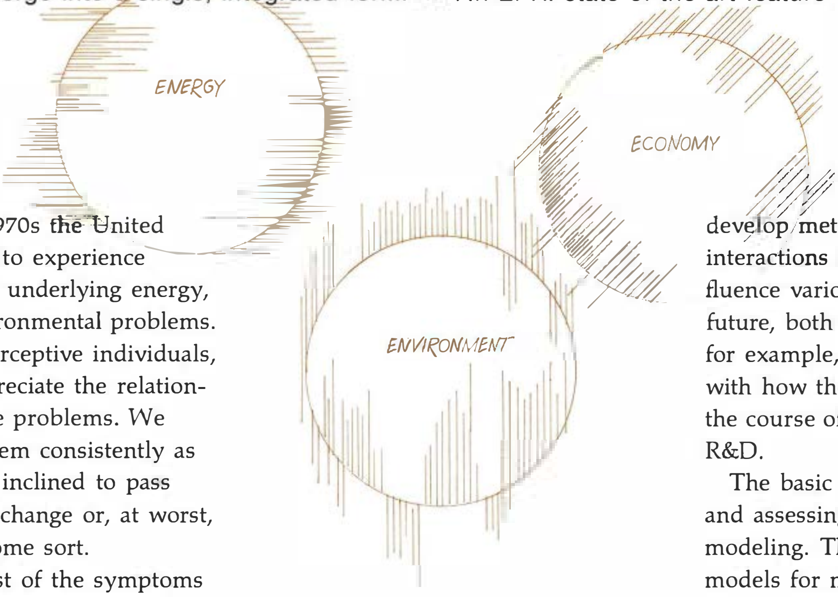
□ "International Electric Research Exchange." Those four words are the name and purpose of an organization, the reason EPRI is a member, the topic of its annual meeting recently held at EPRI, and the title of the article on page 46. Bob Taylor of our public affairs staff was at most of the sessions and wrote the story.

□ It's a long way from the SO_x potential of a ton of coal in Birmingham to the famine potential in a developing country halfway around the planet. But EPRI Advisory Council members went the distance in their confrontation of issues and guest speakers—and each other—at a weeklong seminar on international energy problems. Ray Schuster, editor of the JOURNAL, joined the group at Aspen, Colorado, and he highlights discussions from several sessions in "Advisory Council Hosts Energy Issues Seminar" (page 49).

Linking the Models to Match the Systems

by Jerry Karaganis

U.S. energy and economic systems are becoming more interdependent with every passing year. An evolutionary, nontechnical look at the concepts of systems modeling shows how energy and economic models must converge into a single, integrated form. ▫ An EPRI state-of-the-art feature



Early in the 1970s the United States began to experience symptoms of underlying energy, economic, and environmental problems. Except for a few perceptive individuals, we didn't fully appreciate the relationships between these problems. We didn't even view them consistently as problems but were inclined to pass them off simply as change or, at worst, growing pains of some sort.

Interestingly, most of the symptoms were suppressed by a single remedy: imported petroleum.

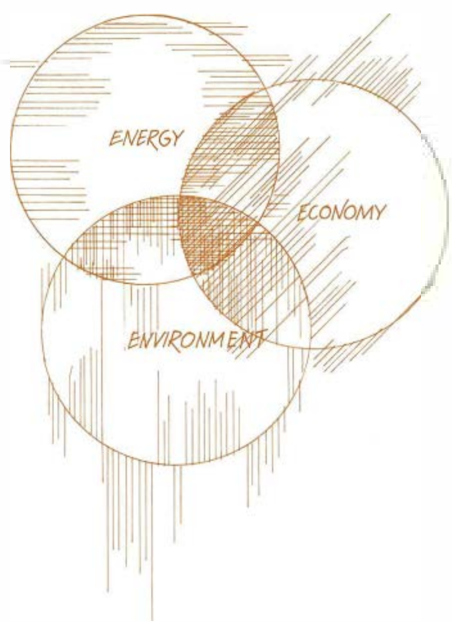
Thus, when the Arab oil embargo hit in the fall of 1973, quickly followed by quadrupled prices from the remaining exporters and a falloff of U.S. oil production, the symptoms reappeared with a new intensity. For most of us, the "energy crisis" was a total surprise, but this time we realized that there were problems.

The oil embargo, its aftermath, and its role in our economic recession, are now history. Perceptions vary as to what the problems were, or still are. But if we have learned a lesson from this experience, the nation will not have to relive it.

One lesson apparent to professional analysts is that our energy, economic, and environmental systems interact. Thus, an imbalance in one can play havoc with the others.

Recognizing this, both government and industry have moved quickly to develop methods for examining system interactions and how they may influence various aspects of the U.S. future, both near and long term. EPRI, for example, is specifically concerned with how these interactions can affect the course of energy and environmental R&D.

Jerry Karaganis is a research staff member of the Systems Program in EPRI's Energy Analysis and Environment Division.



The basic method for abstracting and assessing a system is that of modeling. There are many kinds of models for many systems and for many applications. But the purpose here is not to treat modeling or systems analysis in a deeply technical way. Instead, it is to develop a sense for the modeling process, particularly as applied to energy and economic systems, and to emphasize the need for an integrated model form, the energy-economic system model.

The modeling process

A decision maker is confronted with a problem: What is the likely expansion of the energy system by the year 2000 and what are the likely fuels? He may first draw on available information to answer the question. He may use his own knowledge and experience and combine them with a simple graphic model to extrapolate or project the future. But if his information is based on sketchy or poorly documented facts in which he lacks confidence, he can turn to a modeler who is knowledgeable in the problem area. The decision maker and the modeler agree on assumptions that will affect energy growth, such as population size and the amount of goods and services to be produced. The modeler uses his theoretical and technical background to model the problem by mathematical relationships.

If an appropriate model for the problem already exists, the modeler "runs" it with the agreed assumptions. He interprets the results and presents them to the decision maker, who can either base his decision on these results or repeat the modeling process with different assumptions and, perhaps, additional factors.

If there is no appropriate model, the modeler "builds" one. With his background in the energy field and in modeling, he gathers data and specifies relationships. When he has conceptualized his initial model, he programs it for a computer, documents it, and tests it with historical data. If the model fails to "track" or conform, he starts over. But if the model meets this real-world test, it is appropriate and can then be run with the particular assumptions of the problem.

There are two important and perhaps paradoxical points about this process that should be emphasized.

- The data, the assumptions, and the model itself are well documented and available for inspection. They are as complete, objective, and factual as possible.

- The central role is that of the modeler, not the model. (And certainly not the computer. The computer is only a computational tool.) The

WE ALL USE MODELS

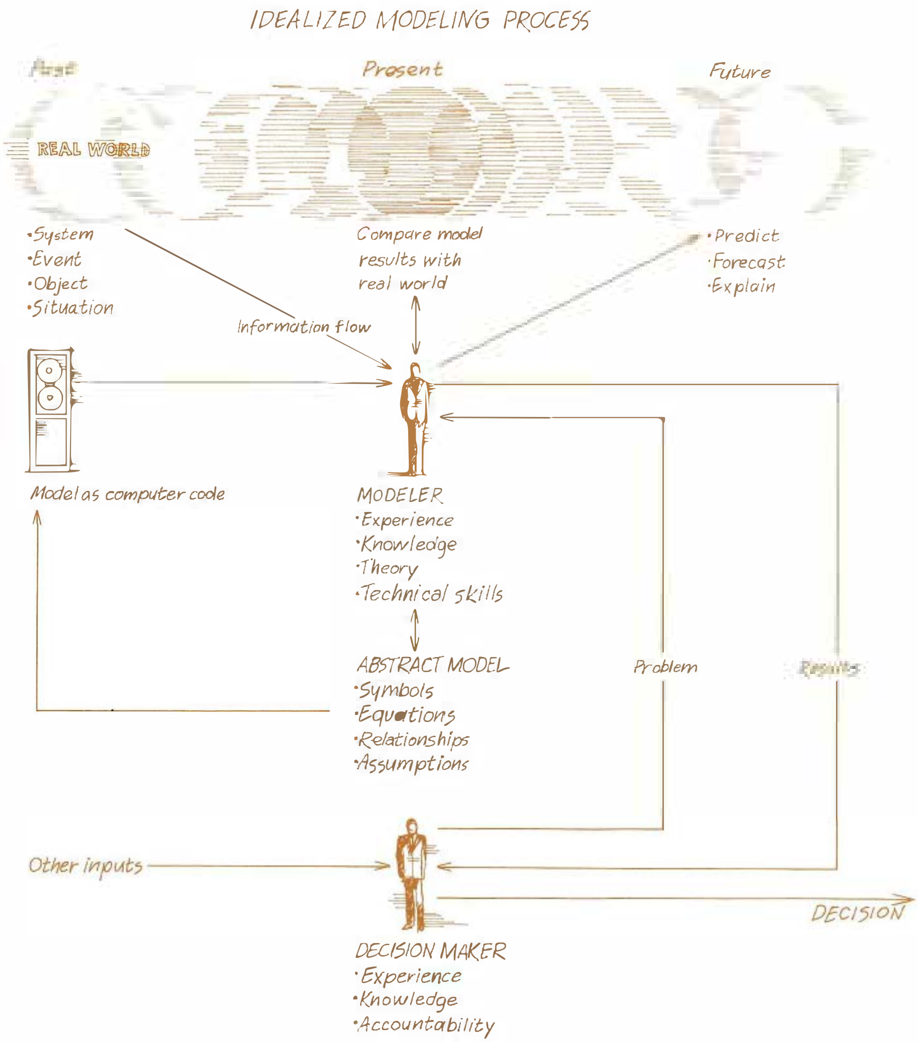
Man is distinguished from other animals by his ability to develop and use tools. Not just physical tools but, more important, mental tools. It is with mental tools that we adapt to the present and plan for the future. One principal mental tool is the model. It is with the model that we learn, solve problems, and communicate.

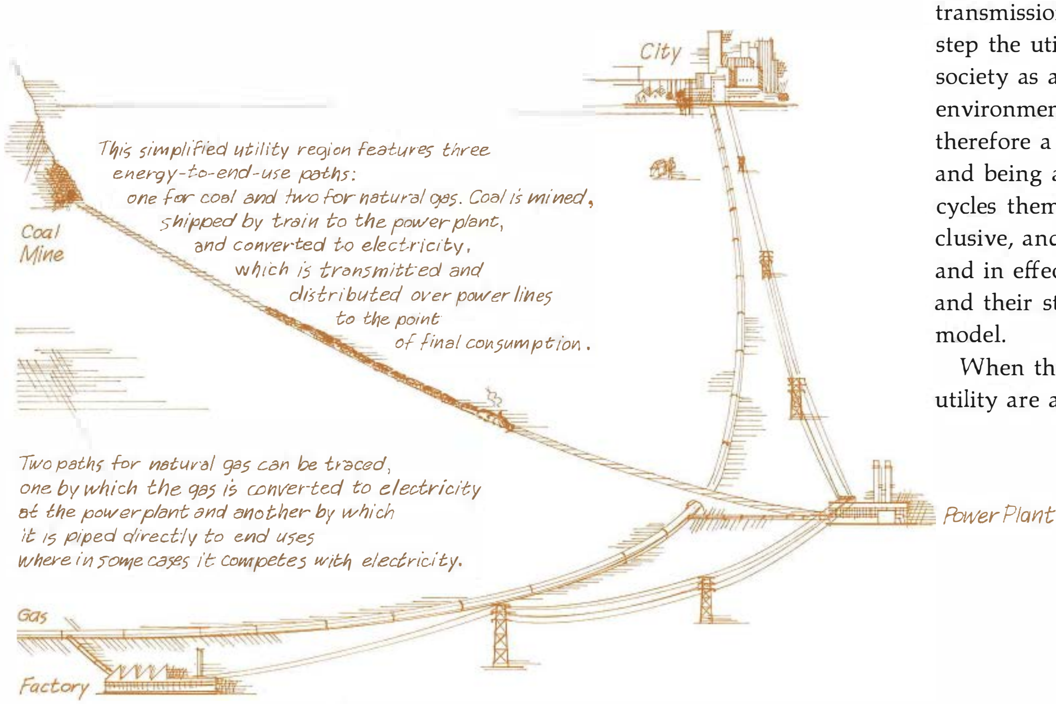
Models have been evolved to meet our needs. Primitive people developed the basic model—language—to survive. As society formed and life became more complicated, there was much more information to process. We developed more versatile models, starting with pictographs and evolving to the more abstract form of written symbols.

A sense of time and of measurement stimulated numeric concepts, and rudimentary commerce brought about the development of accounting models to record transactions. As new lands were sought and explored, maps were drawn to communicate safe trade routes. Most important, we recognized the need to transmit our accumulated experience, so we began to record (or model) our history and experience for future generations.

We devised coordinate systems by the middle of the seventeenth century. Using graphs, we could observe trends in different sets of data. Graphs led to the idea of numerically defined relationships, called mathematical functions, and functions provided much of the impetus for modern science.

We all use models in our everyday life. What do models have in common? What makes them models? Each model represents something in the real world—a system, an event, a situation, an object, or a process. And that is all a model is, a representation of something in the real world by a symbol or abstraction.





modeler must select the factors thought to be influential; he must assume many of the boundary values in a given problem; and he must interpret results. These exercises of judgment, many of them shared with the decision maker, mark modeling as an art, not a science.

Modeling the energy system

Energy system modeling has roots in process or industrial modeling. For years individual electric utilities, petroleum refiners, iron and steel producers, and industrial firms of all kinds have modeled their processes to plan operations, new additions to capacity, and financial requirements. Energy system modeling is similar in that the structure and behavior of a system are modeled, but it differs in purpose, scope, time frames, size and completeness of system, and degree of resolution (simplicity and detail). These similarities and differences become apparent in an example.

The energy cycles of the utility service region sketched here are also the basic elements of an energy system model. They must be further defined by the separate steps in their evolution from raw resource to energy end use (e.g., mining, beneficiation, transportation, conversion to electricity, transmission, and application). At each step the utility, its customers, and society as a whole incur economic and environmental costs. Each step is therefore a decision point affecting and being affected by others. The cycles themselves are not totally exclusive, and they also interact in costs and in effects. Together, these cycles and their steps are the structure of the model.

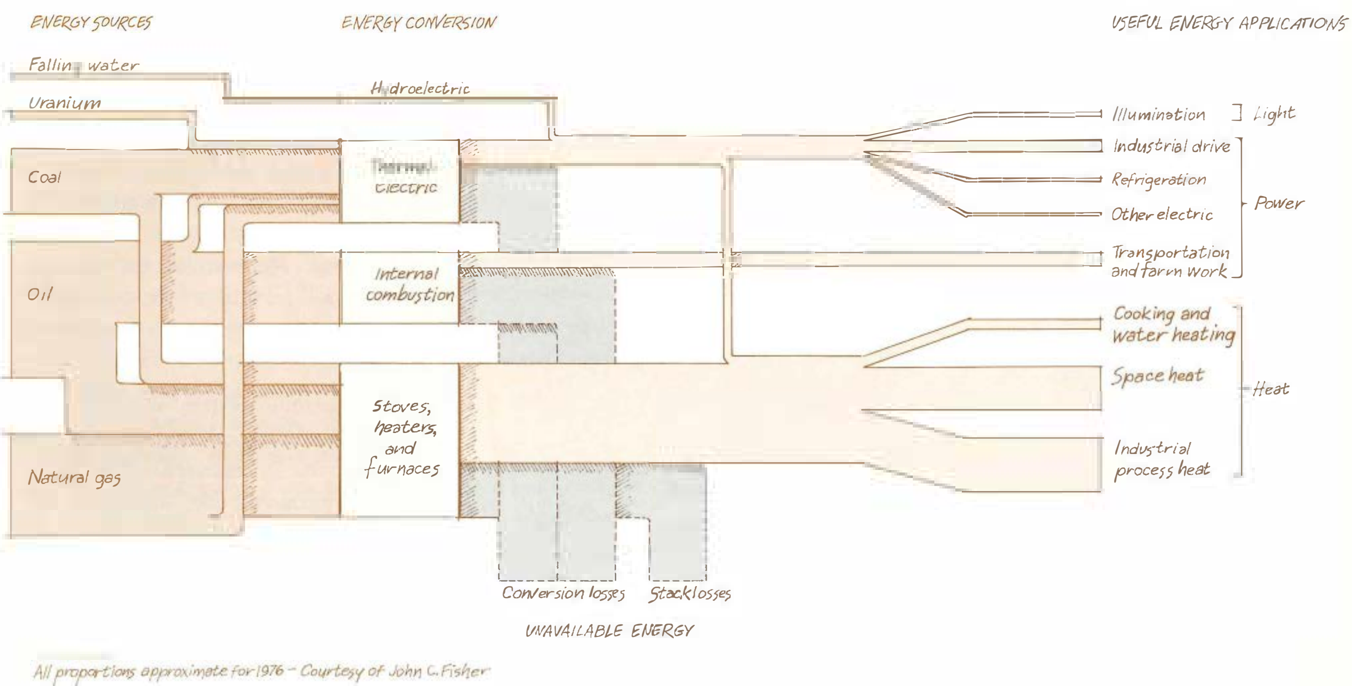
When the rules of behavior of the utility are also known, the system can be modeled. For an electric utility, behavior is prescribed by regulation: to deliver dependable, environmentally acceptable service at least cost. As conditions change with time, the model always selects the energy cycles that are the most economical and environmentally acceptable.

This example of a hypothetical utility and service area portrays elements of an energy system model. But it remains an industrial model because its structure and behavior are interrelated entirely within the boundaries of a single industrial organization. The single utility has human management that consciously and continuously exercises intention and control, thus setting the conditions of interdependency.

Energy system modeling is a generalization of the type discussed in the above example. The system is enlarged to include the U.S. energy network from resources (including potential resources and technology) to end use. The time intervals modeled are lengthened from 10–20 years to 25–50 years. The U.S. energy system is regarded as an integrated whole (even though it lacks the explicit, well-defined management of a single utility). It thus has structure and behavior that can be modeled. Details are replaced by averages and specific cases by general representations. Thus, the specific coal cycle becomes an average coal cycle. It is an average utility industry that buys average coal at an average price from an average coal industry. This averaging continues throughout the coal cycle until average electricity is consumed by average industries, homes, and stores.

Once the average energy cycles are complete for each of the resources, an overall energy system structure can be assembled. It changes constantly, in incremental terms, but looks generally like the accompanying figure for years at a time. Conceptually, it still remains to prescribe and to model rules of behavior for the system that will allow it to select the preferred energy cycles. Neither task is simple. The concepts are straightforward, but the execution is very difficult. Myriad details of structure and myriad intricacies of behavior must be traced and reduced to logical form and, ultimately, to mathematical functions.

Furthermore, data must be gathered from a sufficient number of points in the system so that the model is a useful representation of the system. For example, in the industrial model of the utility, optimal energy cycles were selected with the sole criterion that the utility provide dependable, environmentally acceptable service at least cost. But in the U.S. energy system, utilities are not isolated. As a group, energy resource producers, transporters, processors, and users exhibit mixed behavior. Some industries can hold supplies to reap a greater profit over time, while others are required by regulation to meet demand and to have limited profits. All such behaviors must be captured in a realistic energy system model.

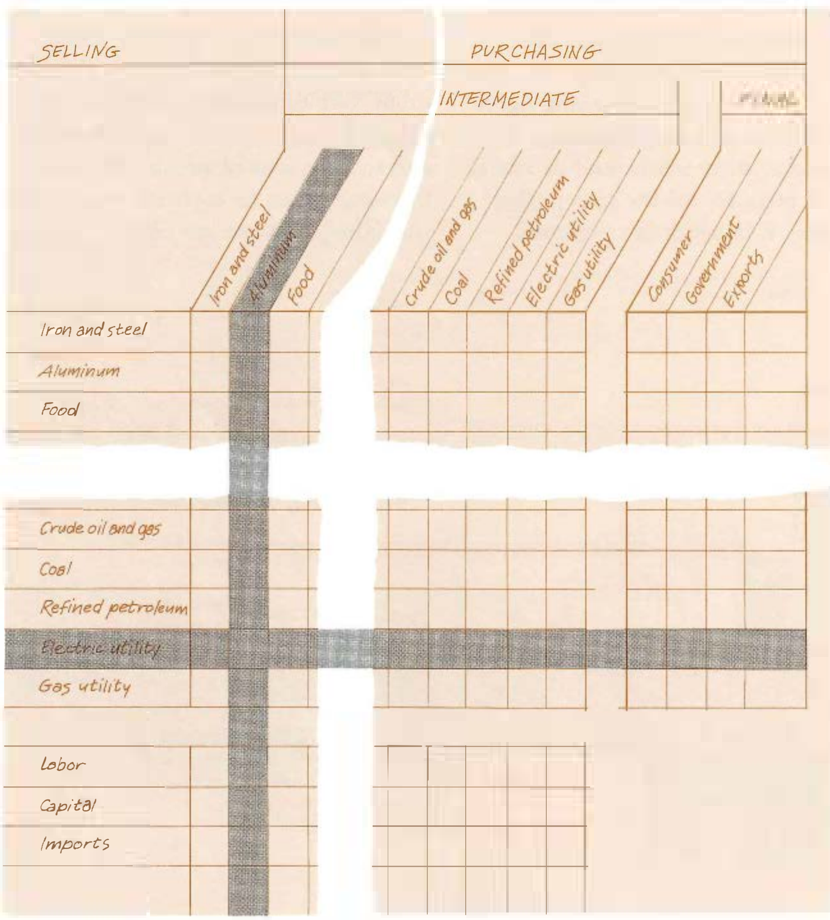


Energy paths from source through conversion to end use portray both structure and behavior of the system. Structure is depicted by direction and route – origins, crossovers, convergences, divergences, and destinations. Behavior is revealed by width proportionate to the selected quantity. For the most part, behavior is chosen on technical grounds. But what is the role of economic factors? What will it be in the future?

Modeling the economic system

Economic system modeling deals with the structure and behavior of the national economy, with industries as the basic producing and consuming units. It also evolves from the specific to the general. Companies are grouped (aggregated) to form industries. Goods and services are purchased, combined, and consumed in the production of other goods and services. Industries thus interplay, and their inputs and outputs are tallied and related, not in physical terms but in a single homogeneous measure, dollars.

The interindustry chart organizes the elements of the U.S. economy. Just as the energy system model incorporates decision points where costs are incurred, so must the economic system model. For any industry, the decision elements are the dollar value of ingredients it must employ to make its product or to perform its service: inputs of steel plate, paper, paint, vinyl, wire, glass, process heat, capital, and labor. Each ingredient (and its possible substitutes) has cost implications for the industry itself, its customers, and society as a whole.



Purchases and sales among industries define the structure of an economic input-output table, a virtual interindustry chart of the U.S. economy. As with the energy system, various component behaviors must be defined for modeling. Capital, labor, and imports are goods and services available for sale in addition to industrial product outputs. Similarly, consumers, government, and exports are end users outside the matrix.

Once the structure of the model is complete, the economic modeler prescribes its rules of behavior. A basic rule is that industry responds to change in price. Thus, if the price of coal becomes high compared with the price of electricity, the iron and steel industry will begin to change its methods and its equipment so as to use more electricity and less coal as a resource for power or process heat.

The energy-economic relationship

It is obvious today that the energy and economic systems affect each other. Major energy shortages affect lifestyles and the ability of industries to produce desired outputs; conversely, economic downturns reduce the demand for energy, with consequent ripples of cost and price effects through all fuels and facilities. But it is not obvious exactly how these behaviors are interrelated.

Until recently, modelers had little need to consider these cross-system or feedback effects. The apparent abundance of energy resources and their resultant low cost made the energy system seem essentially independent of economic system influences.

- The energy system modeler used ad hoc methods independent of the model to determine major economic variables, such as energy consumption, discount rates, and energy, labor, and capital costs. He assumed the economic system would adjust to the mix and cost of energy fuels determined by his analysis.

- The economic system modeler ignored technological change and, even more important, resource depletion and environmental considerations. For example, his analyses did not include the breeder reactor, shrinking natural gas resources, or pollution abatement.

Both modelers stopped short of capturing the essential connections between energy and economic systems. The links weren't perceived to be significant; thus, there was little value set on integrated modeling until five years ago.

Basic research today is only slowly piecing together the structure and behavior of these systems by examining their past and present performance. Historically, energy growth has been highly correlated with economic growth. Historically, the nation has relied increasingly (up to 70% of our energy use today) on inexpensive, clean natural gas and crude oil.

But the situation is changing. The nation appears to be running critically short of natural gas, and domestic crude oil production is continuing to decline from its high in 1970. There is evidence (though still highly uncertain) that the energy system is gradually shifting from gas and oil to coal and nuclear power. Will a shift from inexpensive energy cycles to more expensive energy cycles affect the economic system? Will energy consumption and economic growth continue along their highly correlated paths?

Such questions challenge the energy-economic modeler to link the energy and economic systems. They are the kinds of questions that have been so urgently addressed—yet so differently viewed—in recent studies to define bases for U.S. energy policy.

For example, the Ford Foundation's Energy Policy Project, emphasizing energy conservation, used energy-economic modeling to identify and evaluate foreseeable effects of such a course. The FEA's Project Independence team employed energy-economic modeling to project volumes and costs of domestic fuels, and their implications for the economy, if we were to become self-sufficient by 1985.

Much of today's energy R&D is concentrated on techniques for changing electric utility and other industrial production processes to reflect the effects of fuel substitution, new technologies, environmental costs, and increased energy prices. As modelers are successful in linking the energy and economic systems, the resulting analyses will be of great benefit to the electric utility industry and to government policymakers.

Problems and directions

When large-scale energy-economic modeling began less than five years ago, funding was limited. The modeling was initiated not as a planned discipline but more as a way to correlate data for an energy study. Yet it rapidly aroused curiosity among government and industry decision makers—partly from serious interest and partly as a defensive reaction to an unknown planning tool. Since that beginning, energy-economic modeling has received generous support from government and industry, and today it shows signs of becoming a true discipline.

Energy-economic modelers need to uncover the strengths and weaknesses in their field, find its research frontiers, and consolidate its gains. For example, the field needs better data and information, better ways to communicate, and better standards to guide it. All in all, it needs to be developed by dedicated individuals capable of making it a profession, capable of protecting it from misuse, and capable of making it useful in systems analysis.

EPRI has become one focal point of these needed efforts because an important part of its work is to provide the electric utility industry with a state-of-the-art energy-economic modeling capability. Within the Energy Analysis and Environment Division, specific responsibility lies with the Systems Program staff.

Because energy-economic modeling is a new field, more effort has gone into model building itself than into serious application and analysis. As a result, many of the models to date are incompletely understood. Different models exhibit different behavioral patterns despite their similar structure. The causes and implications of these differences are often unclear.

But the number and variety of models in existence warrant a systematic effort to reveal their strengths and weaknesses and to gain understanding of where and how they can be used most effectively. Such is the purpose of a new research project sponsored by EPRI: Energy Model Comparative Analysis, begun last August and known among its participants as Forum.

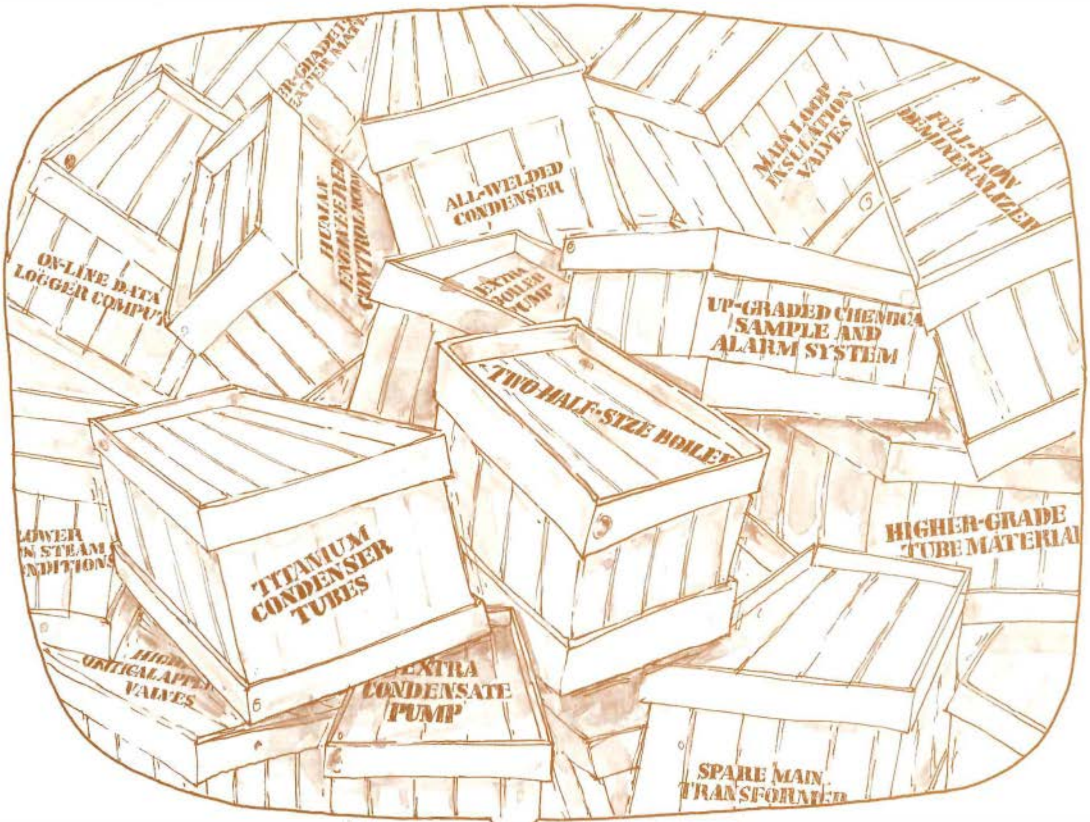
In Forum, decision makers and modelers are joining together to apply energy-economic models to important problem areas. These individuals have expertise in management, engineering, science, economics, and systems analysis.

During its projected four-year life, Forum should provide continuous, constructive feedback between model users and model developers.

Forum members will meet three or four times each year. On each occasion they will choose a set of questions to be studied and select the models that appear best suited to the desired analysis. Of course, the questions may have to be adapted to the models' structures and behaviors.

After the models have been run, the results will be critiqued for plausibility, consistency, and completeness. Forum members will attempt to relate differences in results to differences in the models' structures and specified behaviors. Such explorations will expose misunderstandings and bring to light the most critical assumptions—both good and bad. Finally, Forum members will share their findings in a series of highly readable reports that will be widely circulated to decision makers and modelers.

In the course of this work, Forum will examine the models EPRI has under development and will provide a valuable critique of EPRI's own modeling research. Thus, by the end of next year, EPRI will be supplying the electric utility industry with basic facts and understanding of the new and important field of energy-economic modeling.



How Can We Improve Power Plant Reliability?

by Joseph A. Prestele

A broad-scale effort on reliability assurance is being carried out at EPRI for both fossil-fired and nuclear generating plants. The projects range over the entire field from materials and design to components, operation and data systems, reporting, and analysis. ▫ An EPRI program article

Programs for improving and assuring power plant reliability are fast becoming everyone's favorite game—and if not dealt with in perspective, could become the only game in town. Like quality assurance, reliability assurance cuts across traditional disciplines. Consequently, when applied within any given management structure, it reaches broadly across organizational lines, with all the management problems and dangers that that involves.

In considering their reliability programs, utilities and designers would do well to heed the lessons hopefully learned in the development of their quality assurance programs because the pitfalls are common: the temptation to superimpose an entirely new layer of management discipline over that already in existence, the seductive urgings to be given the opportunity to provide programs that will allegedly solve all the utilities' reliability problems, and so forth. This is, of course, not intended to suggest that valid elements of reliability engineering should not be incorporated into management efforts aimed at reliability improvement, but rather that they should be incorporated as much as possible into existing organization structures so as to avoid traps such as those mentioned.

There is an implication in the current pursuit of reliability improvement that those principally involved in building power plants are somehow not responsible for—or even worrying about—how reliable they will be or what their quality will be. This is simply not true. A quality product that will perform reliably at an acceptable cost is what sound engineering is all about. I do not doubt for a moment that the engineering professionals currently in industry, possessing as they do sound engineering backgrounds and having the freedom to apply that knowledge, have the capability to solve a substantial majority of the utility industry's reliability problems.

Notwithstanding all this, there is clearly an opportunity—and, in fact, a need—for EPRI as a national organization to supplement industry efforts in reliability improvement by focusing programs on improved component performance, better material selection, and shorter outage times. Hopefully, then, with the assistance provided by EPRI's programs, those professionals whose job it is to design, build, and operate the nation's power plants will be provided that increment of support needed to do their jobs more effectively.

Major EPRI programs on power plant reliability improvement are being prepared and conducted both in the Fossil Fuel and Advanced Systems and the Nuclear Power divisions.

FOSSIL-FIRED PLANT PROJECTS

Activities of the Fossil Fuel and Advanced Systems Division (FFAS) of EPRI have been structured to suit the historical nature of the nonnuclear utility business. There are significant differences between the backgrounds of the nuclear and the fossil-fired sectors of the electric utility industry. The fossil-fired sector is, of course, older and has developed in a traditional, independent way, relatively free of the constraints and regulations that apply to nuclear plants. Plant deficiencies and problems have been dealt with by direct action of utility-vendors, assisted by voluntary exchanges of data and experiences at professional meetings.

This rather informal situation has resulted in a public data base on faults and performance that is less comprehensive for fossil-fired than for nuclear plants. FFAS supplemented the published data by holding a series of meetings within the past year with representatives of some of the major utilities that are operating units of 600 MW or larger. The discussions were useful in identifying the major components that tend to fail most frequently and their failure modes. They have been referred to constantly in the formulation of the EPRI research program.

The discussions were also informative about the historical backgrounds of some of the present reliability problems. Many of the large units now operating were specified and ordered on the assumption that there would be a continuing supply of low-price, good-quality, uniform fuel—coal, oil, or gas. Plans based on the use of a closely specified range of coal permitted the acceptance of designs with narrow margins in pulverizer, coal- and ash-handling, soot-blower, and fan capacities. And in all cases, furnace size, auxiliary power, and structural weight tended to be reduced to economic minima. The recent increases in fuel costs, requirements for use of alternative low-sulfur supplies, and a general deterioration in fuel quality have introduced changes in operating conditions and in system economics that in many cases have called for the further complication of cycling large units. Poorer fuels and cyclic operation were frequently cited as factors seriously affecting plant reliability.

It is now clear that existing plants, plants under construction, and plants to be specified in the near future must all be able to perform reliably and economically under increasingly severe load-cycling conditions and with a range of fuels that may be dictated by future supply and environmental restrictions.

The emphasis of the Fossil Plant Performance and Reliability Program is on short- and mid-term projects that will improve the performance of existing units and also contribute to the specification and performance of new plants.

Program objectives

The objectives of the program are to analyze the factors responsible for plant performance below design expectations and to initiate research to correct those

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situations by improved operating procedures, design modifications, or materials. In time, the work will include projects on component testing and will lead to the drafting of specification guidelines and quality assurance provisions.

The most important interface in this program is that with the utilities, as the program's immediate concern is with current practice and experience. The subprograms are therefore based on equipment subassemblies, which is generally in line with the subdivision of expertise within the industry. Any resulting overlap of scientific disciplines will be dealt with by internal controls and communications.

The subprogram areas are steam-supply systems, turbine generator systems, and ancillary plant systems. The materials group, which is not part of the reliability subprogram staff, will be heavily involved in all three areas. From a chemical standpoint, it is also logical to think in terms of the total water-steam circuit, which includes parts of all three systems.

During the next year, providing a better insight into the root causes of failures and substandard performance will be the emphasis in all subprogram areas. There is no single source for data of this type, although the records compiled over the years by EEI provide a valuable statistical background. These records are being examined through a coordinated EPRI–EEI effort and by participation in meetings of the Prime Movers' Committee.

As has been mentioned previously, EPRI has held six informal meetings with some of the largest utilities in different parts of the country to discuss their most pressing concerns about plant reliability. These meetings are to be followed next year by surveys of utility experience on specific plant components, subsystems, or failure mechanisms, which will provide a much more detailed data base by the end of 1977. From this improved data base, projects will be established to address operating and reliability problems, to reduce and shorten planned outages, and to improve the design standards for new plants.

Subprogram objectives

In the steam-supply subprogram there are three major problem areas: fireside fouling and corrosion, steam-side oxide exfoliation (oxide scaling off in thin sheets from steam-generator tubing), and pressure tube failures. The first two contribute to the third but do not account for it entirely. Projects under way in these areas have already made it apparent that oxide exfoliation is strongly related to heating and cooling cycles. Water treatment and chemical control are also important. There is a background of excellent work that is related to nuclear plants on which the fossil plant program can draw, but fossil plants will have their own particular problems, which the program will address as necessary.

Improved materials and proper selection of materials are clearly important to reliability, and work is being carried on to assess and improve the resistance of boiler tube steels to both steam and coal-ash environments. There are also prospects of using acoustic techniques to detect and locate tube leaks at an earlier stage and work is in progress to assess this.

Work on boiler fouling aims to develop a better understanding of the transformation undergone in the flame by inorganic constituents of coal. This is relevant to work in programs on coal cleaning and blending. Other aspects of fouling to be addressed include operating conditions and combustion. By 1980 it should be possible to provide the industry with operating guidelines that will alleviate both steam-side and gas-side problems and incorporate experience gained in studies of plant performance under cycling conditions.

An increasingly important characteristic of fossil plant operation during the next two decades will be greater load following and cycling, which will call for better capability for predicting dynamic behavior and better understanding of the impact of thermal stress on mechanical integrity. In a word, better plant models will be needed for specification, design, evaluation, and control. These will be developed by manufacturers with EPRI direction to assure that they meet utility needs. The models will form the basis of the more advanced control and operating guides after 1980.

Design criteria

As progress is made in problem solving, EPRI's emphasis will shift to the definition of design criteria, which will lead to guidelines for plant specifications, backed by in-service testing of critical components and structures made of improved materials. These efforts will have an impact mainly on new plants scheduled for operation in the 1980s.

A major concern of turbine generator suppliers is cyclic damage to the turbine and its components. The most common causes of outage are low-pressure blade failure and high-pressure blade erosion. Low-pressure blade failure is usually caused by fatigue, and an appreciable amount of fatigue damage may occur at speeds below synchronous operation. High-pressure blade erosion is related to the exfoliation problem in the steam-supply system.

Corrosion mechanisms aggravate fatigue failure. Control of the turbine atmosphere and knowledge of the behavior of blade materials under combined corrosion and static-plus-cyclic stress will be studied. At the same time, tests are to be run under cycling conditions to obtain data for the validation of thermal stress models.

The studies should provide important contributions to the development of operating guides and control systems that will appreciably reduce risk of plant damage while ensuring high performance capability. A first operating guide is expected to be available by 1979; there will be further development through 1981.

In-service monitoring and improved inspection techniques will be developed to reduce risk of major damage due to unforeseen failures. Improved materials for rotors and blades will be of major importance both in larger machines and in cycling machines. EPRI's role in this effort will be to catalyze materials development and to appraise new materials in realistic test programs. New materials will be available beginning about 1979, but full-acceptance criteria will probably require testing for two years after that. An exception is titanium alloy for low-pressure blading, which is already undergoing testing. Subject to satisfactory review, this alloy could become available quickly if it is found to be economically justified.

Turbine bearing failures are most common at low speed. So the special lubrication needs at startup and rundown will be addressed early in the program, with the objective of providing both future and retrofit options by 1979.

The use of a range of materials with widely different properties in addition to the very large mechanical and electromagnetic forces in generators pose severe mechanical problems. On-line monitoring systems will be investigated and specific materials problems addressed. Already there is a prospect of improved end-ring materials, and better conductor materials and joints are to be studied.

The ancillary systems subprogram will include fans, pumps, valves, feed heaters, pulverizers, fuel-handling equipment, and condensers. This is a diverse area in which attention is presently focused on feed pumps and condensers. Feed pump failure studies have already exposed generic weaknesses in certain designs, which have been corrected either by the vendors or independently. Performance surveys will be initiated on other specific items in the first year of the program. At the same time, overall plant reliability studies will help in the development of component design criteria, against which current designs will be assessed and specification standards developed. EPRI will encourage product development by assisting with utility tests and by assuring the objective reporting of results.

NUCLEAR PLANT PROJECTS

Within the Nuclear Power Division Systems and Materials Department, there is a current set of projects and programs to improve the performance and reliability of selected power plant systems and components. The results of many of these projects are expected to be useful for improving selection of operating conditions and procedures for existing plants or for improving design and functional specifications for new plants or replacement components.

Major efforts are in progress in the following areas.

- Tube thinning, cracking, and distortion (PWR steam generator)
- Pressure boundary, materials properties, stress analysis, and fracture mechanics—mainly on pressure vessel steels
- Corrosion and cracking behavior of primary system piping (BWR)
- Nondestructive testing and in-service inspection, including improved quantification of code-approved methods and development of advanced methods for field use
- Fuel rod and core materials, especially behavior with load change and during postulated LOCA
- Failure analysis efforts and field diagnostic methods to determine root causes of malfunctions

Investigations of turbine rotor materials are also under way. These relate primarily to embrittlement and fracture mechanics of turbine rotors in order to better quantify acceptance and rejection criteria rather than to improve design. Collectively, these projects aim to reduce the frequency of outage events or power reductions attributable to the affected components and to decrease the impact when an event does occur.

Extensive coordination efforts are carried on with industry, government, and research organizations to advise on utility needs and priorities and to monitor these efforts.

A pressure vessel program is directed toward assurance of the present and continued high integrity of pressure vessels, a paramount consideration of reactor safety and productivity. No significant additions to or lengthening of forced outages have occurred as a direct result of pressure-vessel-related problems; however, the long-term code inspection requirements, plus changes in inspection technology, provide a substantial incentive for R&D that can help reduce the duration of scheduled inspection outages.

The plant chemistry and corrosion subprogram deals with a significant source of outage and repair efforts—namely, that of cracks or leaks in high-pressure piping and tubing. While leaks or cracks in boiler tubes have been an operational problem for almost 75 years, the heightened impact of plant outages resulting from such leaks or cracks in nuclear units, together with the added effect of in-plant radiation levels on plant maintenance, has increased the incentives for reducing the frequency of such events.

Testing and inspection

Another program treats nondestructive examinations and in-service inspection. Nondestructive examination (NDE) is specified by code and licensing requirements. Improvements in some aspects of code-approved methods are desirable to improve sensitivity and repeatability and to minimize dependence on subjective interpretations by the operators. NDE methods are also relevant to failure diagnosis of operating components and to failure prevention. In these cases the incentives are directly reflected in unit productivity improvement.

A plant materials and processes subprogram has been developed to profit from the lesson of experience that improving component reliability in a specific application, in many cases, depends mainly on a better specification and control of basic materials and fabrication processes. In this subprogram processing technologies have been identified that potentially could improve material properties and thus service behavior. For example, the application of electroslag melting, vacuum arc refining, or improved conventional casting technology may provide means by which to produce more uniform and reliable steels.

Fuel performance

The overall goal of EPRI's LWR fuel rod performance studies is to develop the data base and the analytic tools that will increase plant availability and capacity factors by making fuel rods more reliable and plant operations more flexible. Although currently focused on PWRs and BWRs, some of the methodology developed in this program will be applicable to other fuel rod and reactor designs.

The program consists of related research at the fuel rod, fuel bundle, and whole core levels. The program emphasis will shift with time toward actual power reactor experience at both the bundle and the core levels. The current program includes heavier emphasis on rod and materials behavior, separate effects tests in the Halden and Studsvik test reactors, out-of-reactor tests, and fuel behavior modeling.

Finally, the failure analysis and plant component reliability effort has the following purposes.

- To help determine the relative importance of potential improvements in different components or systems

- To provide (using "root-cause" analysis) the sharpest technical focus for R&D on design, operation, or materials, and for the testing of remedies

- To evaluate (using "potential failure" analysis) preliminary indications that may foreshadow malfunctions or failures and to determine whether preventive maintenance is warranted

This effort focuses on root-cause and statistical analyses involving austenitic piping, steam generators, turbine rotors, and vessel nozzles. Related work has centered on improving diagnostic and analytic techniques—both the instrument-based data and the stress analysis, fracture mechanics analysis, and duty cycle analysis that are required for root-cause determinations.

High-reliability plant

Given the present enormous incentives to improve reliability, availability, and capacity factors, a program in the Engineering and Operations Department of the Nuclear Power Division has been approved and is being organized. This program will explore both the principal limitations that deter improved nuclear plant performance and those changes in design that are required to eliminate or to mitigate those deterrents.

Historically, we have built generating stations that have not performed at desired availabilities. With the cost of money to the utility industry having about doubled in the last 8 to 10 years, we need to explore the building of stations that can be operated with availabilities of 90%, or even 95%. It is worth a large effort to attain these operating factors in order to reduce reserve capacity requirements. A more difficult problem will be to determine the real cost of the changes that will result in the probability of achieving this high availability.

Assuming that about 200,000 megawatts of nuclear generating capacity will be in operation by 1985, a 1% improvement in capacity factor can be equated to the reduction of an industry financing need for approximately three 1000-MWe nuclear units at a cost near $3 billion.

Virtually all current nuclear units were specified and built in an era when the cost incentives for productivity gains were less than one-fifth of present values. The traditional utility–equipment-supplier relationships in problem solving and productivity improvement have been severely affected by a quantum jump in cost factors.

The change in the distribution of plant costs makes it unrealistic to expect equipment suppliers to solve problems unilaterally. The nuclear steam supply system (NSSS) and power conversion equipment suppliers have seen their portion of the plant capital cost drop from 40% to less than 15%. Some 30–50% of plant cost is now in the form of interest and escalation.

This program should lead to raising the national nuclear generating productivity. It should also ensure that EPRI has a water reactor program that is focused on long-range problems, whereas many of the present water reactor projects are focused on solutions to the operating problems being experienced currently in the field. Such a program is required in EPRI because the manufacturers, architect-engineering firms (AEs), and individual utilities do not have the resources to carry it out by themselves.

The program methodology would first identify four plants that are performing well, one furnished by each of the principal NSSS vendors. Project teams representing the principal organizations involved would then set about the task of identifying those items that limit the availability of the plants and those changes that would be needed to increase that availability, assessing in the process which changes could be effected on existing plants and which could be applied only to new plants.

It would also consider the interrelationship of such factors as the small benefit in shortening refueling time unless the balance of the plant could be returned to operation within the same time period. Typically, shutdown length is not determined by refueling per se but by other functions, such as identification of failed fuel, turbine maintenance, pump seal maintenance, surveillance requirements, and other balance-of-plant maintenance.

Data systems analysis and upgrading

Finally—and also within the Engineering and Operations Department of the Nuclear Division—efforts are under way to deal with the subject of power plant data systems as they relate to improving reliability. As an initial step in scrutinizing the data presently available to industry, EPRI has undertaken an in-depth study of each and every licensee event report for 12 nuclear power plants to discern the nature of the circumstances causing the events reported and their trends, and ultimately to provide better understanding and guidance following such events.

EPRI is also about to begin an effort that will scrutinize the three major data banks: namely, EEI's data bank on equipment availability, the EEI–Southwest-Research Nuclear Plant Reliability Data System,

and the NRC's so-called gray book data bank—this time with a twofold purpose.

First, as with the licensee event report project, it is hoped that insights into the causes of power plant unavailability can be developed that will allow a sharper focus on where industry's efforts might best be applied, not only in areas involving R&D but also possibly in improved operating techniques, maintenance programs, and any other areas that might surface in the analysis.

Second, and maybe equally important, is a goal that follows naturally from such an analytic effort. That goal is identification of ways in which these data systems might be upgraded, not necessarily (and indeed hopefully not) by the inclusion of more reported data but rather by the furnishing of *better* information.

Much attention has been given the subject of power plant data banks in recent months. On June 2 about 50 persons representing a number of utilities, AEs, manufacturers, consultants, government agencies, professional societies, EPRI, and representatives of the EEI committee structure and staff met in the offices of the Federal Energy Office in Washington. Among the issues discussed during the course of the day were the need to open the EEI data banks to unrestricted public access and the need for industry to formulate and implement an early warning alert system to provide prompt dissemination of information having generic interest concerning events affecting plant availability. A most interesting thread that wove in and out of the discussion related to the end use of present data banks and what was generally perceived by those present to be a low level of end-use value. To help solve this problem, EPRI has also undertaken a research project aimed specifically at establishing a direct dialogue with a large number of data bank users—utilities, manufacturers, and architect-engineers—to identify ways of upgrading the major data banks in operation to increase their end-use value.

Another major perception that has been evolving within industry is the basically fragmented and not fully organized way in which the existing power plant data systems have evolved. In addition to the data banks mentioned, there are others, less visible but no less burdensome in their reporting requirements, administered by other private and government agencies (federal, state, and local) and all contributing to the workload the power plants ultimately must shoulder.

Recognizing all this, an effort is under way within the EEI committee structure and with EPRI cooperation to develop a scope document for an effort to identify just what the total data reporting burden is, and then, out of that assessment, to develop what will approach a truly national power plant data-reporting system.

Smaller size, better appearance, and especially, reduced land and structure costs have become increasingly important for urban substation design. With the advent of gas-insulated substation equipment, major advances have been made. Today, for ac system voltages of 500 kV and higher, fully insulated, metal-enclosed ("dead-tank") equipment may be less expensive than its air-insulated equivalent, and a 90% reduction in size can be achieved. This kind of "compacting" has also been done at lower voltages so that substations can be fitted, for example, into the basements of downtown buildings.

A similar evolution is also needed in dc technology, particularly because the space requirement for air-insulated dc converter stations is substantial. EPRI-sponsored research in dc terminals responds to that need. Specifically, it carries out work begun under auspices of an Electric Research Council (ERC) working group in 1971. Based on that group's recommendation for a demonstration project, ERC's HVDC Task Force selected Consolidated Edison Co. of New York, Inc., as the host utility. Later, in August 1974, EPRI awarded a contract to General Electric Co. to develop, design, and install two interconnected converter terminals —a prototype dc link. Con Edison is supervising the installation and will operate the completed facility.

The main purpose of the project is to demonstrate compact, dead-tank, outdoor, low-profile converter technology. A secondary purpose is to demonstrate the effective use of dc transmission for direct power infeed to ac networks in the heart of a large city. One eventuality, of course, is the location of HVDC converter stations in the basements of large buildings. As the project continues, it should also serve as a testing medium for improved compact equipment yet to be developed.

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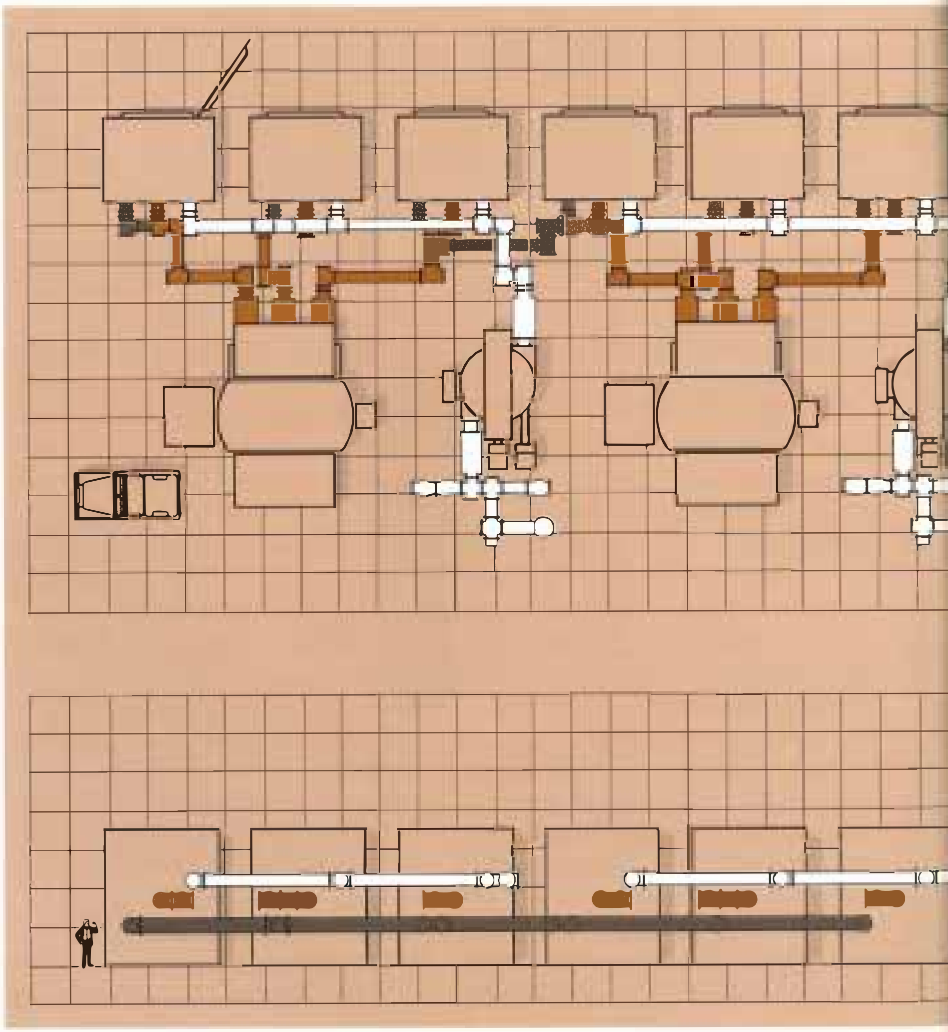
What should be compacted?

Since the start of the EPRI project, a good deal of debate has taken place on the extent of compactness needed in dc terminals. There seems to be a consensus that compacting the bus connections from transformers to valves and from valves to the dc line (including disconnect switches, grounding switches, bushings, transducers, and voltage-measuring devices) is basic, and this will be demonstrated by the prototype dc link project (Figure 1).

Those who have worked out layouts of connections between transformers, valves, and other dc equipment are aware of the space consumed and the cost burden of crisscrossing the busbars. Gas bus and switches would save considerable space and may well be the most economi-

Compacting DC Terminals

by Narain G. Hingorani and Stig L. Nilsson



cal way to build converter stations for voltages of 400 kV and higher. To complete the line of compact dc components, gas-insulated, neutral bus-load-break switches and metallic-return transfer-breakers will also be desirable sometime in the future.

The question of compacting the valves has caused the most debate. A modern air-cooled, air-insulated thyristor valve is housed in a building with a clean, controlled air environment and flat internal walls to minimize clearance requirements. Such a building is therefore quite compact and raises the question of whether further compacting by gas-insulated valves is necessary. EPRI has chosen to develop liquid-cooled, gas-insulated, dead-tank valves for the following two reasons:

□ Liquid cooling improves valve performance because it allows direct dissipation of heat into the air, unlike the air-water-air cooling chain for conventional air-cooled valves. The first air-water heat transfer is eliminated by direct liquid cooling of the thyristors. This permits a smaller valve structure and a better utilization of thyristor current-carrying capability. Hence, liquid cooling is desirable for converters.

□ The further step of replacing the air enclosure with an SF_6 enclosure for the valve containment, affording final reduction in valve size and elimination of bushings, may be less significant, at least from the standpoint of space saving. Initially, it may even be more expensive. In time, however, gas insulation of valves could be a most satisfactory valve containment, especially in cities where the ground area and the height of buildings must be minimized. The use of oil for valve insulation and cooling is not very attractive because of the associate increased stray capacitances within the valve. This factor increases the size of the damping circuits, thereby increasing the heat dissipation in the valve and consequently reducing the overall efficiency of the converter. It also increases the fire hazard.

Compact bus connections and thyristor valves are the focus of R&D for a prototype dc link between two Con Edison substations in New York City. Construction and operation should prove the feasibility of compact dc terminals. □ An EPRI technical article

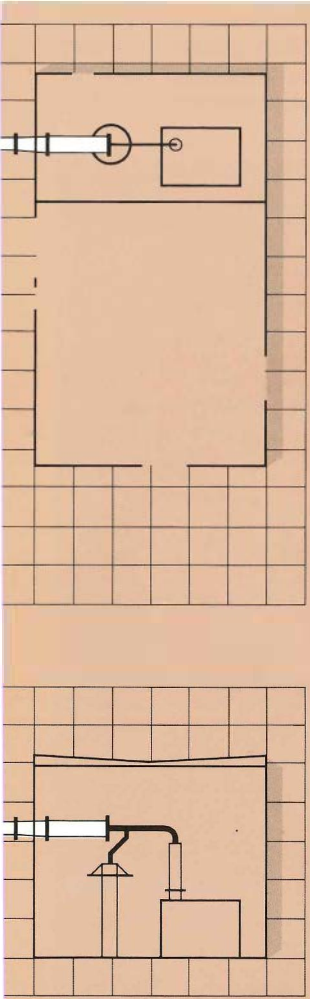


Figure 1 Close grouping of potheads, transformers, and thyristor valves in plan view of Astoria East terminal reveals space saving made possible by gas-insulated bus. Elevation view emphasizes low profile of gas-insulated valve tanks.

Research, development, and demonstration of compact ac and dc harmonic filters were omitted from the prototype dc link project because the extensive ac cable systems of the Con Edison substations are effective in short-circuiting the harmonic currents generated by the converters. They also provide sufficient reactive power capacity for operation of the dc terminals. But the need for compact filters is not disputed. The necessary compensation equipment alone, which includes the ac filters and the needed switchgear up to the converter transformers, typically occupies more than half the space needed today. Compacting the filters is therefore vital to the whole exercise, but it can be explored as a separate project. EPRI has sponsored such a project, targeted to demonstrate compact capacitors and filters by mid-1979.

Deciding the research scope

From these considerations, EPRI established three major R&D areas that define the project:

- Development of a gas-insulated, dead-tank dc bus system for all bus sections from the converter transformers to the dc cable potheads
- Development of liquid-cooled, gas-insulated, dead-tank converter valves
- Development of two types of dc cables with cable potheads and splices

The first two areas are under study by EPRI, while the third is an independent Con Edison project intended to provide design experience for 600-kV dc cables. Another facet of Con Edison's involvement is the 138-kV ac supply cables selected for the link. The utility will use solid dielectric ac cables for the first time.

As part of the project, a fault data acquisition system and a data logger for HVDC terminals are being developed and will be installed in the prototype dc link to aid in data collection during test operation. The system will include equipment useful for future HVDC projects or large ac substations.

Adapting to the site

The 100-MW rating of the prototype dc link created the problem of finding a project site that would allow for realistic operation at full power without costly facilities for the dc circuits joining the ac/dc converters together. The converter terminals should also be located at two points electrically remote from each other, as seen from the ac sides, to allow for experiments with stabilization of ac systems via the dc link.

A suitable location was found in Queens, New York City, where two large-capacity Con Edison substations, Astoria East and Astoria West, are only about 700 m (2000 ft) apart. No direct connections exist between the two substations, since that would create short-circuit duties on the substation equipment beyond the design limits, even though Con Edison's ac network itself provides a tie between them.

The Astoria substations are used principally as outlets for five steam-generating units and several gas turbines. The dc link is not essential to the operation of the power system, but it provides a useful method of transferring power between the two substations as an alternative to the reconnection of generating units from one bus to the other. The link is therefore designed to transfer power in either direction (Figure 2).

The 100-kV voltage rating of each converter is not sufficient for realistic stress of the dc equipment. For research purposes, therefore, a bias set has been added, which will be used to elevate the dc system to a 300-kV potential of either polarity. Thus, the maximum dielectric

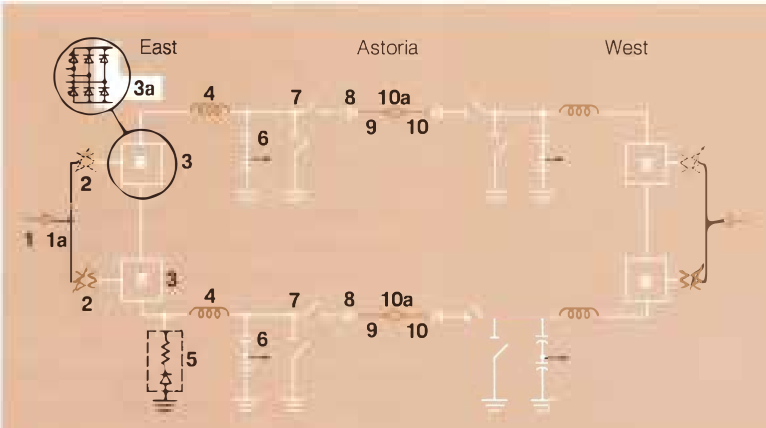


Figure 2 Functional scope of dc link is portrayed by identical dc terminals and 2000 ft of oil-filled cable between them. Summary specifications prescribe the major design operating conditions.

- GIS equipment or busbars
- Air-insulated equipment or busbars
- Oil-insulated or solid-dielectric-insulated equipment

1 138-kV solid dielectric underground cable
1a 138-kV ac cable potheads
2 Converter transformers with primary load tap changers (LTC)
3 Two-way, 3-phase (6-pulse) converter valve bridge comprising three twin valves
3a Twin valve
4 DC smoothing reactor
5 300-kV bias voltage supply (reversible)
6 DC potential transducer
7 DC disconnect and grounding switch
8 DC cable pothead
9 DC medium-pressure oil-filled underground cable
10 DC high-pressure oil-filled underground cable
10a DC cable splice

Specifications	
AC system (both terminals)	
System voltage	138 kV
Frequency	60 Hz
Short-circuit capacity	10,000 MVA
DC system	
Bus system voltage	400 kV
Converter system voltage	100 kV
Bias voltage	300 kV
Rated current	1000 A
Rated power	100 MW
Minimum power	10 MW
Converter terminal	
Valve bridges per terminal	2
Twin valve rating	50.0 kVdc
No-load voltage	59.3 kVdc
Cooling medium	Freon 113
Insulation medium	SF_6
Transformer rating	62.8 MVA
Transformer secondary voltage	44.4 kV/25.65 kV
Transformer impedance	22.4% (62.8-MVA base)
Transformer LTC range	17.5%
Smoothing reactor inductance	62.5 mH

stress of the link is 400 kV. However, the bias supply constitutes a high-impedance path to ground, and consequently, the system is not directly grounded. This necessitated including a smoothing reactor in both sides of the converters at each terminal. It also complicated the protective scheme.

A relatively conventional control system is used. The master equipment is located in the control house of the East terminal. The West terminal is unmanned and therefore has facilities only for local emergency operation. Some features of the control equipment that eventually will benefit the utility industry are a new reactive power control function, equipment for simulated diode rectifier operation, and an advanced dc potential transducer. The last is an adaptation of the old static voltmeter principle, which is compatible with the compact bus system.

Designing the bus system

Compact gas-insulated bus is used from the bushings on the converter side of the transformers to the potheads for the dc cables. The design is such that the whole converter terminal is on a concrete pad measuring only 18 m $\times$ 40 m (60 ft $\times$ 130 ft). However, the resultant power density (about 0.12 MW/m^2) is not a relevant figure of merit for the project because the terminal design, due to its 400-kV insulation represents a power-carrying capacity far exceeding its 100-MW rating.

The behavior of a gas-insulated bus system under ac stresses is well known. But even though the properties of the gas itself are known for dc stresses, bus equipment has not previously been built and tested as a system for dc applications. This had to be taken into account in the development program.

There are fundamental differences between ac and dc insulation stresses. One is that dc voltage distribution is governed by the resistive properties of the materials, whereas ac or high-frequency stresses are determined by the capacitive properties of the materials. However, insulation media for HVDC must be able to withstand not only dc stresses but also ac surge voltages superimposed on the dc. Care also has to be taken to ensure that insulating materials are not electrolytic conductors, which could cause materials damages under the influence of dc stresses.

Other problems the designer faces are associated with foreign particles in the gas environment. Free conducting particles can have a catastrophic effect on the integrity of the gas system, causing short circuits between the bus and the enclosure. They also tend to adhere to the insulator surfaces. For reliable operation, the bus system must be protected, and the choice is between removing all particles from the bus enclosure or confining their movements. Three approaches have been developed for the dc link: cleaning techniques, which have been successfully tested under laboratory conditions; particle traps, which confine particles left in the bus structures after assembly; and conditioning procedures, which will be used before energizing the system.

With all the variables involved, the design of gas bus support insulators is not a trivial problem. However, based on design and test work already completed, insulators will be built in two versions—one with small holes for equalizing gas pressure between compartments and one solid insulator for isolating separate gas compartments. The latter is to be used at the interfaces of valves and gas bus sections.

Careful design has also marked development of the electrodes in elbows, T-connections, and X-connections in the gas bus system. Disconnect and grounding switches have been adapted to and tested for the dc application as well. Furthermore, stab connectors (removable links) have been developed to facilitate bus conditioning in the field and maintenance of the system (Figure 3).

A new instrument has been developed for dc voltage measurements on the gas

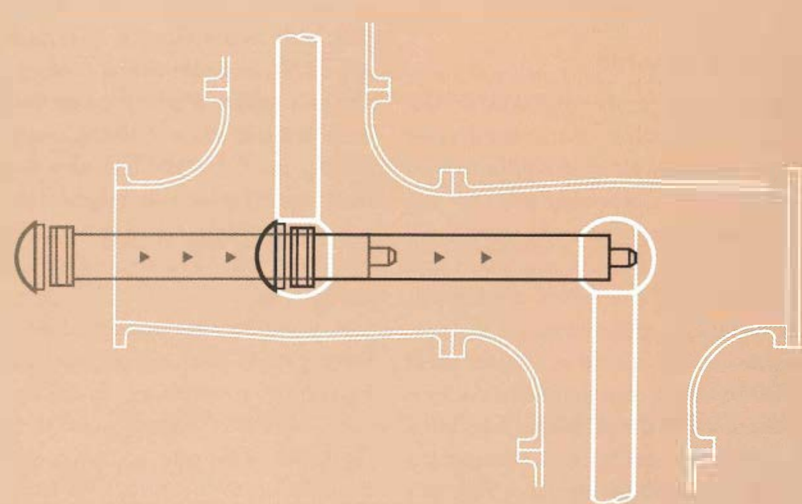
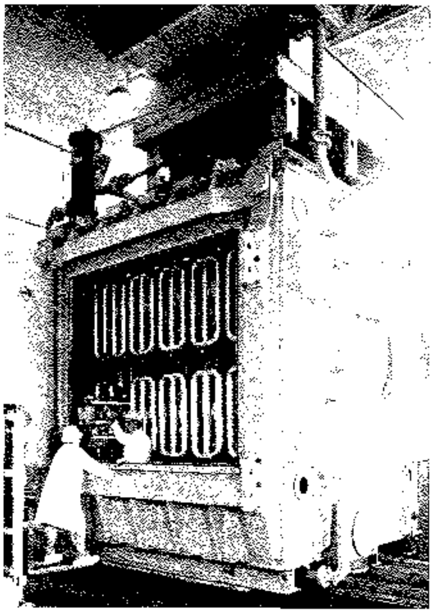


Figure 3 Stab connectors permit easy makeup of elbow and tee connections in gas bus—and also ensure complete disconnection for safety during maintenance work.

Figure 4 Valve panels are accessible for maintenance via bolted door on twin valve tank. Electrostatic shielding around panels is to maintain an even voltage distribution across the valve.



bus system. It uses the well-known static voltmeter principle to sense capacitive displacement currents from the bus and produce a voltage output proportional to the electrostatic field. Much smaller than the conventional resistive voltage dividers now used for air-insulated systems, the device is compatible with other gas-insulated components.

Compacting the valves

Thyristor valves for the prototype dc link are based on existing air-insulated valve designs, but with major modifications to accomplish the compacting goals for the project and to meet the requirements for a dead-tank design. Gas insulation and liquid-cooling of the valves are the primary means of compacting.

SF_6 insulation is used at a lower pressure in the valves than in the bus sections in order to avoid the problems associated with pressure vessel design. Close spacing of components within the valve increases the capacitive coupling between them, but because SF_6 has the same dielectric constant as air, the coupling phenomenon remains manageable.

A compact valve requires a small, efficient means of removing heat from the various valve components. A liquid coolant medium, circulating through small heat sinks, meets the requirement. Liquid Freon is ideal in many respects and was selected for the project. It has a low dielectric constant, minimizing the coupling between thyristor modules and their enclosure. It is also nonflammable, nontoxic, a good insulator, and an efficient thermal conductor.

A number of materials have been used in new combinations in the valves, requiring effort to ensure their compatibility for reliable valve operation. Examples are optical fibers, Tefzel cooling tubes, and Freon used in the presence of SF_6. Laboratory aging tests have been a part of the materials selection process and are being continued to determine possible adverse, long-term effects.

Leak prevention and protection have been studied extensively. To detect major SF_6 and Freon leaks and prevent catastrophic failures, monitoring systems have been developed and made a part of the valve assemblies. In addition, long-term migration of both SF_6 and Freon is a concern. For example, small amounts of SF_6 will gradually penetrate the Freon cooling system and need to be removed. This is done by modifying the expansion vessel for the cooling system. It will function both as a separator to remove dissolved SF_6 from the Freon cooling liquid and as a pressurizer to prevent the Freon from boiling, since it has a low natural boiling point. A problem also exists in that some Freon will migrate into the valve tank. Such leaks are normally very small and will have no adverse effect on the system.

A valve is built from modules called valve panels. Each valve panel contains thyristors, overvoltage protection circuits, and gate control circuits for the thyristors. The gate control signals are brought up to the panels via fiber-optic links. Connections are also made to each panel for thyristor cooling circuits and between panels to form a single string of series-connected thyristors within a valve.

Each valve tank houses two valve assemblies with arresters for overvoltage protection. The tank is a welded structure with bolted doors for maintenance access. A forced draft, dry-type heat exchanger for the valve cooling system is on the top of the tank (Figure 4).

The effects of materials and structures that penetrate or bridge the gas space between energized parts of a valve and its tank have been extensively tested under laboratory conditions. Tests have been supplemented by computer studies, primarily through field plotting. As a result, it has been possible to optimize the electrostatic shields surrounding the valve panel structure to give an even voltage distribution across the valve for voltage surges.

Attention has been given to ease of operation and maintenance of the valves. Viewing ports, monitoring circuits, and various gages will give the operator a clear awareness of the internal state of the valve. The access door and a special valve handling cart will facilitate efficient replacement of panels, which should be helpful in maintaining a high availability of the dc system.

Expectations and plans

Successful R&D leading to design and testing of the first prototype components indicates that compact dc terminals will be available when needed, even if final testing and operation produce some problems. These would be normal and are one reason for building pilot or demonstration plants. Even unforeseen problems may lead the way to needed improvements.

The dc link will be available to EPRI for at least five years after the expected acceptance of the terminals in early 1978. During that period, the facility will be used for several purposes: demonstrating compact terminal technology to interested utilities; demonstrating the usefulness of dc links for power infeeds to cities; optimizing the dc bus and other equipment; and demonstrating compact ac filters, power modulation concepts, reactive power control, and a new, integrated operation-monitoring system.

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson Director

PLUTONIUM RECYCLE

Experience to date indicates that the behavior and safety characteristics of mixed-oxide (MO_2) fuel are entirely satisfactory and that there are no apparent performance limitations created by the addition of small amounts of PuO_2 to UO_2. Consequently, the EPRI plutonium recycle efforts have focused on developing improved MO_2 performance statistics, building confidence and acceptability in the use of MO_2 fuel, and providing the analytic methodology required for assessing the characteristics and economics of plutonium recycle.

Table 1 lists the present projects and their contractors. The projects are intimately related to the EPRI nuclear power programs and have been singled out here for emphasis.

RP396, which seeks to develop the data base required to understand MO_2 densification characteristics, was initiated in recognition of the need for extending the UO_2 densification results obtained in RP131 (completed in 1975). It is being carried out at Battelle, Pacific Northwest Laboratories in

Table 1
EPRI PLUTONIUM RECYCLE PROGRAM

Research Project	*Project Title*	*Contractor*	*Comments*
72-2	Use of Plutonium in Water Reactors	General Electric Co.	Postirradiation examination of plutonium assemblies
118	Advanced Recycle Methodology	Nuclear Associates International Corp.	Development of analytic capability for analyzing plutonium recycle
300	Strategies for Plutonium Utilization	Stanford University	Methodology for fuel-cycle decision making with plutonium recycle
306	Multiple-Cycle Plutonium Utilization	Exxon Nuclear Corp.	Prototypical irradiations in Big Rock Point
310	Study of a Denatured Plutonium Fuel	General Electric Co.	Evaluation of the feasibility of a "denatured" fuel cycle
348	Clean Critical Experiment Benchmarks	Battelle, Nortnwest Laboratories	Benchmark data for testing nuclear data
396	Plutonia Fuel Densification	Battelle, Northwest Laboratories	Extension of UO_2 project to develop data base for MO_2 modeling and fuel performance
497	Quad-Cities Plutonium Recycle Measurements	General Electric Co.	Prototypical irradiations in Quad Cities-1

cooperation with seven industrial cosponsors.

The extent of thermal and irradiation environments on changes in the microstructure and homogenization of MO_2 fuels will also be investigated. Several fuel types will be fabricated, characterized, irradiated, and then subjected to postirradiation examination. Effects arising from differences in pore-size distribution, PuO_2 particle size, PuO_2 loading and PuO_2 distribution will be evaluated. Two capsules have already been irradiated to different exposure levels in the General Electric Co. test reactor. The low-burnup capsule was discharged in March and the high-burnup capsule in June.

MO_2 Fuel Used in Commercial Reactors

Just completed, RP72-2 characterized the behavior of 11 MO_2 rods previously irradiated in the Big Rock Point reactor to burnups between 23,000 and 30,000 MWd/t. Nine of the rods contained annular pellets. Detailed metallographic examination of fuel rod sections and microprobe analysis of fission product transport have been carried out.

No unique performance problems associated with PuO_2 additions to UO_2 have been identified, and fuel-column-length changes have been consistent with densification and swelling results in UO_2 fuels. No evidence of annular fuel pellet redistribution has been observed.

Microprobe analysis showed the expected inhomogeneities and X-ray imaging showed no discernible radial plutonium migration. On the other hand, cesium was observed to be peaked at the outer edge of the pellets and near the top of the fuel column.

Also under RP72-2, five UO_2–MO_2 prototypical "island design" assemblies were designed and fabricated for insertion in the Quad Cities-1 reactor. RP497 is continuing this effort to provide both nuclear and performance data from these assemblies, which have now completed one cycle of irradiation. The MO_2 fuel contains half annular and half solid pellets. Both interim (nondestructive) and destructive examinations will be carried out. The first set of poolside examinations and gamma scans has been completed and 15 selected rods have been removed for isotopic analysis and possible later postirradiation examination. The data developed are intended to verify the safety, economics, and performance of this fuel in modern BWRs.

A parallel project is being carried out under RP306. This is a cooperative project with Exxon Nuclear Corp., which (under a contract with Consumers Power Company) has designed and fabricated a number of MO_2 assemblies presently being irradiated in the Big Rock Point reactor. As of the beginning of 1976, 22 MO_2 assemblies of two different designs were present in the core. The project includes monitoring the irradiation of the MO_2 assemblies and operation of the reactor with significant amounts of plutonium. Fuel performance will be monitored at each cycle shutdown and destructive analyses emphasizing isotopic measurements will be carried out. In addition, the plutonium from 4 of the assemblies will be recovered at the end of their irradiation and new assemblies will be designed for later reinsertion of this plutonium into the core.

Under RP118, Nuclear Associates International Corp. has developed an analysis capability that is suitable for fuel management and core operations support studies, including cases of mixed-oxide fuel. This computer code package is now being distributed to the utility industry, and additional benchmarking continues. The goal is to demonstrate that this capability can be used with confidence in both UO_2 and mixed-oxide cases.

Although the effort is presently emphasizing particular research requirements, it is expected that the priorities will shift as the needs of the industry change and are redefined. *Program Managers: B. A. Zolotar and J. T. A. Roberts*

EXPERIMENTAL STUDIES ON PELLET-CLAD INTERACTION

The outstanding current example of limitations on plant capacity attributed to deficiencies in fuel-element design is designated pellet-clad interaction (PCI). While failure rates have been kept to modest levels, this has been achieved largely by the utilities' adhering to vendor recommendations on permissible rates of overall and local changes in power levels. These limitations, while workable, are expensive in terms of plant output lost from partial capacity operation during the slower increase in power.

Observations of PCI-induced failures suggest that fission products generated in the fuel contribute to the resultant failures, thus implicating Zircaloy stress corrosion cracking (SCC) as a failure mechanism. Most investigators accept the view that the release of embrittling fission product species (most likely iodine or cesium) and an applied stress are prerequisites for power-ramp-induced failures, although the relative contributions of chemistry and stress remain to be resolved *(1–5)*.

EPRI-sponsored research proceeds from the assumption that PCI-induced failures are a manifestation of a Zircaloy SCC phenomenon and is directed toward developing an understanding of the underlying mechanisms responsible for the observed cladding failures so that remedial actions can be prescribed. Significant progress has been made in characterizing PCI-induced cladding defects and fission product chemistry in PWR fuel rods and in simulating Zircaloy SCC in the laboratory. The key results obtained to date follow. The projects reviewed are part of the research on LWR fuel rod performance discussed in the September JOURNAL (*6*).

Power Reactor Fuel Examinations

Observations of increased coolant iodine activity during cycle-1 operation of the Maine Yankee reactor prompted a nondestructive poolside inspection and a destructive hot cell examination of a representative number of fuel rods, Combustion Engineering, Inc. (RP586, Task C), with the objective of determining the primary cause of cladding failure (*7*).

Sipping tests performed during the first-cycle shutdown showed that nearly all assemblies with perforated rods were from Batch B (batch designations define different initial enrichments). Of 43 failed assemblies, 41 were from Batch B and only 1 each from batches A and C. Visual inspection of 30 assemblies confirmed the sipping results.

A subsequent poolside inspection program was undertaken, involving the disassembly of four fuel bundles and the removal and examination of individual fuel rods. Fifteen perforated rods were found in the 2 Batch B assemblies examined, along with 1 perforated rod from each of the batches A and C assemblies. It was noted that the failures were appearing during the first increases from 75% to 88% and 95% of core power and that the Batch B assemblies were generally the highest power assemblies in the core. Thirty fuel rods were subsequently selected for the hot cell examination, including both failed and sound rods.

The hot cell examination program included measurements of fission gas release, microstructural studies of the fuel, fission product redistribution measurements, and metallography and fractography of partial (incipient) cladding through-wall cracks. The pertinent results follow.

Fission gas release measurements showed two distinct populations: low-release rods exhibiting less than 1% fractional release and high-release rods exhibiting 11–15% fractional release. Seven of the 10 sound Batch B rods shipped to the hot cell were in the high-release group. Metallography showed extensive equiaxed UO_2 grain growth only among those rods. Significant densification of the irradiated fuel pellets was also observed. Fission product redistribution, as reflected by cesium gamma-scan peaks at pellet interfaces, was also common to the high-release population. Additional evidence of fission product redistribution was obtained from visual and scanning electron microscope (SEM) examinations of the internal clad surface, which revealed localized regions of fission product deposits and of fuel-to-clad bonding. Three types of deposits could be distinguished: sharply defined linear deposits (stripes) opposite cracks in the fuel, relatively heavy deposits at the locations of pellet-to-pellet interfaces, and circular mound deposits that occurred randomly. The chemistry of the deposits will be discussed later.

In three rods from the high gas-release population, partial through-wall cladding cracks were found. The cracks were all normal to the clad internal surface and were located across from pellet interfaces and near pellet cracks. Optical microscopy and SEM fractography of these cracks showed features in common with those observed in out-of-core studies of iodine-induced SCC of Zircaloy (Figure 1). The cracks were tight and showed no visible plastic deformation. The SEM examination showed no ductile dimpling on the crack surface; only flat cleavage planes and river patterns were observed.

Based on the evidence obtained from the hot cell examinations and from the observed strong reactor power dependency of the fuel rod failure pattern, it was concluded that the most likely cause of the failures was pellet-cladding interaction assisted by fission product–induced SCC. The unexpected response of these rods was a direct consequence of the use of unstable UO_2 fuel that was prone to densify and the fact that the fuel rods were not initially pressurized. The resultant high incidence of fuel element failures should not recur because PWR fuel rod designs now routinely incorporate stable (densification resistant) fuels and are initially prepressurized with helium. A new project (RP829) will attempt to locate and characterize incipient cracks produced by PCI in more recent PWR and BWR fuel element designs.

Fuel Rod Chemistry

Under RP455-1, Stanford Research Institute (SRI) has treated the interaction between fission products and cladding on the basis of available thermodynamic data, with the goal of providing a model to account for the formation of the deposits observed on the Maine Yankee cladding and of relating fuel rod chemistry to the observed SCC of Zircaloy (*8*).

The chemistry of the Maine Yankee deposits consisted of:

▫ Linear deposits opposite fuel cracks, containing nodules rich in zirconium, together with some uranium and cesium. A few cesium-iodide crystals were also identified.

▫ Heavy deposits of a ceramiclike compound across from pellet-to-pellet interfaces that contained cesium and uranium. These deposits showed a cesium concentration gradient, with the layer closer to the cladding being richer in cesium.

▫ Circular mound deposits appearing at random locations, which were similar to the pellet-to-pellet interface deposits in both appearance and composition.

▫ Pieces of fuel were bonded locally to the cladding by a material with the same constituents as the interface deposits and the circular mound deposits.

Tellurium was also found locally in conjunction with iron on the clad surface.

The primary mechanism responsible for the formation of the observed fission product deposits is believed to involve

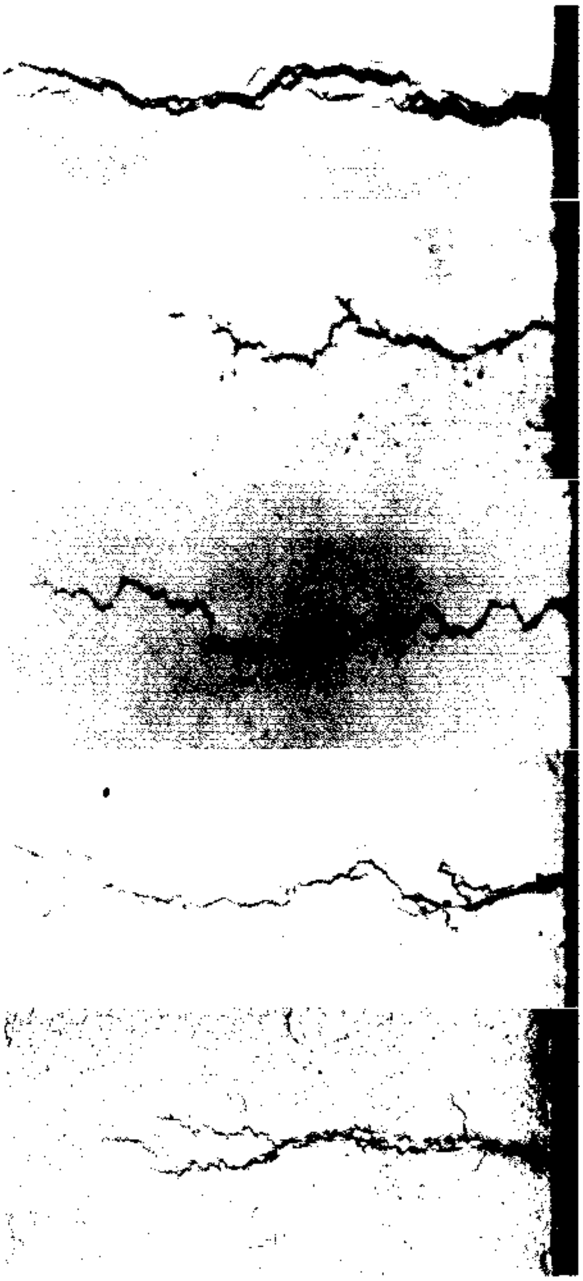


Figure 1 Comparison of cracks (~270 ×) in Zircaloy cladding exposed to iodine environments: (a) unirradiated cladding cracked in iodine vapor at 300°C; (b) irradiated cladding (fluence = 7×10^{24} n/m², E > 1 MeV) cracked in iodine vapor at 300°C; (c) crack in a section of cladding from a fuel element that failed following an increase in power in a test reactor; (d) crack in a section of cladding from an intact element of a bundle that failed following an increase of power in a power reactor; (e) crack in a section of cladding of an intact element from the Maine Yankee reactor. *Photos a–d courtesy of British Nuclear Energy Society, London, from* Nuclear Fuels Performance, *1973.*

vapor transport of the volatile fission products, especially cesium. These species are released from the fuel at high temperatures (presumably by the same mechanism that leads to release of the gaseous fission products), travel along cracks in the fuel pellets, and deposit on the cooler cladding surfaces. The compounds deposited on the cladding are probably Cs_20, Cs_2UO_4, CsI, and Cs_2Te, based on the elements observed at the cladding surface and the fuel rod chemistry. Detailed calculations were required to rationalize the formation of these compounds because the compounds cannot be directly detected and it is not likely that the fuel releases these elements as the compounds noted above.

Relation to Fuel Rod Failures

The details of the observations and the proposed mechanisms for the formation of cladding deposits may not be strictly applicable to normal LWR fuel operation because of the unusually high temperatures in the early Maine Yankee fuel rods. Nevertheless, the observations of cracking are generally consistent with reported data (*1, 4, 5*) and provide the background information from which one can infer the existence of the stress and environmental conditions that are necessary to cause SCC of Zircaloy cladding.

Stresses on the cladding might result, for instance, from the redistribution of cesium to the cooler regions of the fuel pellet, thereby aggravating pellet "hourglassing." Hourglassing, in turn, contributes to cladding strain, since the cladding responds to this nonuniform interaction with the fuel by developing circumferential ridges. Cesium-oxide deposits were observed to bond the fuel pellets and cladding; such bond regions might increase the interfacial friction and thereby act to increase cladding stresses.

Fission products deposited on the cladding included chemical species known to embrittle Zircaloy in out-of-core tests. Elemental iodine embrittles Zircaloy. Based on thermodynamic arguments, iodine in the fuel rod should be combined with the more abundant fission product cesium to form nonaggressive CsI. It has recently been shown, however, that radiolysis can liberate iodine from CsI (*9*). The local deposits of CsI on the Maine Yankee clad might therefore serve as the source for embrittling Zircaloy. The abundant fission product cesium was common to most of the cladding deposits. SRI has established in out-of-core tests that at reactor operating temperatures of ~ 300°C, reactor grade Zircaloy-4 tubing suffered embrittlement, provided that the cesium had a low oxygen content and was contaminated with a trace of iron (*10*). Although it is unlikely that liquid cesium exists in an operating fuel rod, it is possible that small amounts of nonequilibrium species (in line with the radiolytically produced iodine noted above) might be liberated by the high in-core neutron fluxes. It should also be noted that iron is present in UO_2 fuel pellets as a manufacturing impurity and was detected on the surface of Maine Yankee cladding.

Preliminary Findings

The first examination of power reactor fuel under EPRI sponsorship and in laboratory experiments yielded results supporting the view that the dominant mechanism resulting in PCI-induced failures is the SCC of Zircaloy. Iodine, and possibly cesium, are the aggressive agents. Oxides of cesium can act as bonding agents between fuel and cladding, and cesium can migrate to cooler regions of the fuel pellets, thereby resulting in local stress concentrations. *Project Engineer: Howard Ocken*

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LWR BLOWDOWN HEAT TRANSFER

In the design of power reactors, sufficient cooling capability must be provided to keep fuel element clad temperatures below specified values—even in the event of a postulated break in principal coolant loop components, such as the main recirculation loop pipe. To do this, it is necessary to be able to predict reactor system response to hypothetical LOCAs and to evaluate accident-preventing and/or mitigating steps.

As part of the continuing effort to improve and advance reactor safety technology, EPRI is funding research in the area of core heat transfer performance during LOCA blowdown conditions for both BWRs and PWRs. The accident situation receiving the most attention is the guillotine break in the cold leg of the primary piping, with discharge from both ends of the broken pipe. There is a difference in scope between the PWR and the BWR projects, but generally they are limited to the time period extending from the instant the break occurs through the transient critical heat flux (CHF) and further on into the transient post-CHF period.

BWR Blowdown Heat Transfer

This investigation, recently completed, was jointly funded by the Nuclear Regulatory Commission (NRC), General Electric Co., and EPRI and was restricted to the time period between the break occurrence and the actuation of emergency core cooling (ECC) systems. General Electric was the contractor on this project (RP288). The focal point of the investigation was the hypothetical design basis accident (DBA) for a BWR, defined as a full-size guillotine rupture of a recirculation line at the drive-pump suction nozzle (adjacent to the pressure vessel), with discharge from both ends of the pipe break. A further condition of the DBA is that off-site ac power is unavailable, so a power trip to the intact recirculation loop and the reactor feedwater pumps is assumed concurrent with the pipe break.

The principal objective of the study was to obtain information on transient heat transfer following an unlikely, but postulated, rupture of a steam line or recirculation line in a BWR. Specific areas of investigation were the time to CHF, the hydrodynamics of lower plenum flashing and its influence on the bundle thermal response, and post-CHF and lower plenum flashing heat transfer in sufficient detail to evaluate bundle thermal behavior phenomena prior to the availability of ECC.

At the outset, it was agreed that a scaled BWR system test apparatus be designed and built, in which system performance response on a real-time basis would be matched as closely as possible, so that the investigation could be done under LOCA conditions representative of the environment expected in the postulated BWR LOCA. It was further agreed that a full-size, full-power, electrically heated, 49-rod bundle would be used in this investigation.

During work on this project, a number of inherent cooling mechanisms were observed (*1*) for which no safety credit is taken in the BWR LOCA evaluation method currently approved by NRC. These cooling mechanisms consisted of a fluid inventory, which resided in the bundle throughout the blowdown and cooled the lower zone of the bundle; steam updraft cooling in the upper zone by steam generated from flashing due to depressurization and heat transfer to the fluid inventory in the lower zone; and rod rewetting during the lower plenum flashing surge and fallback of the fluid from the upper plenum (deposited in the upper plenum during the lower plenum flashing surge).

These tests demonstrated the importance of various system design parameters on the system thermal-hydraulic and bundle heat transfer responses. For instance, variations in the break cross-section area and initial liquid mass in the annulus had a direct and significant effect on the system response and bundle heat-up performance. Bundle power at initiation of LOCA affected the bundle heat-up response significantly, as expected, but did not affect the overall system response. Large variations in other parameters, such as bypass flow area, lower plenum geometry, pump coastdown rate, and inlet subcooling, had little effect on the system and bundle heat-up responses.

The experimental results were further used to provide a basis for evaluating blowdown heat transfer phenomena. When applied to the test apparatus, current BWR LOCA evaluation methods showed that there is a substantial margin on the side of safety in the prediction of peak cladding temperature. Observed thermal-hydraulic and heat transfer phenomena were evaluated and compared with these methods.

Specific phenomenologically based model improvements for break-flow and void distribution are recommended in the final report. The improved thermal-hydraulic models are expected to provide more accurate and realistic predictions of the system thermal-hydraulic blowdown responses.

PWR Blowdown Heat Transfer

Combustion Engineering, Inc., and EPRI signed a jointly funded contract in 1974 (RP289) to experimentally investigate PWR core blowdown heat transfer phenomena. The test program emphasizes hydraulic simulation of large cold leg breaks, including the large guillotine break. Reactor core transient conditions predicted to occur during a hypothetical LOCA are simulated in the study by imposing core entrance and exit conditions at the test section inlet and outlet. The test sections use electrically heated 25-rod bundles of typical PWR geometry and a single-tube geometry, which is used to study more fundamental CHF phenomena.

The overall objectives of this project are to improve the understanding of transient critical heat flux expected to occur in PWR cores during LOCA blowdown conditions and to determine experimentally the time, location, and distribution of transient CHF.

Two experimental facilities are used in this project:

- A single-tube test facility (STTF) has been built at Windsor, Connecticut, for performance of fundamental tests to gain a better understanding of local CHF LOCA conditions (*2*).

- A rod bundle test facility at Columbia University, in which typical blowdown tests, starting from initial conditions representative of PWR core boundary conditions, will be performed (*3*).

Shakedown testing of the STTF has been accomplished (*4*). An experimental series, consisting of 27 high-powered blowdown tests has been completed in the rod bundle facility with a uniform axial heat flux profile (*5, 6*).

The results of these rod bundle blowdown tests indicate a time-to-CHF ranging from 0.9 to 1.9 seconds. The occurrence of CHF is a result of the rapid increase in test section quality, and it can be seen that CHF propagates rapidly throughout the entire test section length as the flow is expelled from both ends. Evaluation and analysis of the results are continuing.

PWR Single- and Multiparameter Blowdown Heat Transfer

This jointly funded project to investigate single- and multiparameter effects on PWR core blowdown thermal-hydraulic performance (RP494) began at Westinghouse Electric Corp. in March 1976. The objective of this endeavor is to provide experimental data and analysis on key heat transfer parameters during simulated PWR LOCA conditions, including transient critical heat flux and post-CHF heat transfer.

Two phases of testing will be involved: Phase I will focus on controlled, single-parameter transients, which should provide a clear, fundamental understanding of the basic mechanisms and yield data specifically useful to develop phenomenological models. Phase II tests will simulate the thermal-hydraulic conditions calculated to occur under both cold and hot leg breaks in PWRs. These data under multiparameter variations will complement those obtained from single-parameter variations under Phase I. The project will also include the analytic effort to calculate the local transient thermal-hydraulic conditions within the test section.

All tests will be conducted in electrically heated 25-rod bundles, installed in the J-loop of the Westinghouse heat transfer facility (*7*). This is a very versatile facility, where one parameter can be varied at a time while all other conditions are kept constant. A final test plan has been agreed on, and testing began in early June 1976.

Transient Critical Heat Flux

Massachusetts Institute of Technology is nearing completion of an experimental and analytic investigation of CHF under flow-reversal and low-flow conditions (RP292). Experiments were performed in a Freon loop with a single heated-tube test section (*8, 9*). Two computer models to predict CHF under these conditions have been developed and validated against the experiment results.

To date, 40 tests have been completed over a wide range of conditions. At low heat fluxes, the drift flux model predicts the experimental data quite well, whereas at high heat fluxes, the homogeneous equilibrium model predicts the data more closely (*10*). The final report is now in preparation. *Project Managers: K. A. Nilsson and R. T. Fernandez*

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R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

ENVIRONMENTAL ASSESSMENT

Aquatic Impacts of Electric Power Plants

EPRI has undertaken a comprehensive study of the environmental effects of thermal power plant cooling on aquatic ecosystems. Effects can be produced through discharge of heated water or of chemicals, such as biocides and anti-scaling compounds. Effects also can be produced by entrainment of the eggs and larvae of fish and shellfish in intake cooling water or by the collection of small and juvenile fish on the intake cooling screens.

These environmental impacts are being studied in three major project areas: population and community impacts, chemical effects, and ecosystem management. There is also a group of support studies. The selection of the three principal research areas was based on recommendations made by a planning workshop in September 1975, which identified 12 problem areas. Workshop participants included industry and government representatives, as well as prominent independent researchers concerned with the impact of cooling systems on aquatic environments.

The first project area is concerned with effects on populations and communities. The fact that individuals of a given species may die or suffer physiological changes as a result of an environmental disturbance does not necessarily imply that the population will suffer a significant decrease in number. Nor does it imply that the community (the composite of species) inhabiting the disturbed environment will be significantly affected. Unlike a human community, the protection of individual members of an aquatic community is not of prime importance. EPRI's assessment of population and community effects involves field studies and is far more complex than assessment of individual effects, at least when the individual effects are large enough to be readily observed.

One such study is the comparison of a cooling-lake fishery in central Illinois with the fishery at a similar lake not used for cooling. Primary production, as well as fish growth, reproduction, food habits, and movement, will be compared. Primary objectives of the project are to make an ecological and economic evaluation of the cooling-lake fishery and to develop a mathematical model for management of the fishery. It is hoped that the results can be applied to other cooling lakes in the Midwest.

In another study a general methodology will be developed to assess population and community effects associated with entrainment and impingement of fish and shellfish populations. The methodology will consist of an array of analytic techniques for population and ecosystem assessment, and criteria for selection of techniques applicable to specific situations. Limitations of each technique will be examined, and data, time, and cost required for application will be specified. Ecosystem assessment techniques to be considered for inclusion in the methodology are analyses of spatial variation in community structure, temporal variation in diversity measures, differences between observed and theoretical species distributions, biological indicator associations, niche pattern, community stability, ecological energetics, and ecosystem models. The methodology will be tested at lake, river, estuary, and ocean sites.

A third study involves the detailed synthesis and analysis of previous cooling-impoundment studies. These studies have been given special emphasis because if there are ecosystem and population effects associated with the operation of cooling systems, these effects would be most readily observable in small quasi-closed bodies of water (e.g., cooling impoundments).

The second project area involves the examination of current and anticipated chemical effects: the effects of dechlorinated effluents; alternative strategies for controlling growth of mussels at water intakes; development of optimum chlorine dosage procedures to control algal growth on condensors and minimize potential detrimental impact on the environment; and determination of the accuracy, sensitivity, and potential interferences of various chlorine-monitoring procedures.

The third project area, ecosystem management, is an approach to environmental assessment that considers the capacity of the ecosystem to support a combination of industrial, municipal, and recreational demands while preserving (and conceivably improving) environmental quality. The most commonly applied approach to environmental assessment is to measure the isolated environmental effects of a single activity, such as the construction and operation of a coal-fired power plant. But rather than focus on assessment of the ecological effects of a single activity, ecosystem management concentrates on understanding the essential structure and dynamics of the entire ecosystem (river, lake, estuary, or coast) in order to best integrate the ecosystem with industrial, municipal, and recreational needs in an environmentally acceptable manner. Over a three-year period, a general methodology will be developed to assess the integrated ecological impacts of multiple power plants situated on a single body of water. The intention of the project is to determine how these plants interact with the aquatic ecosystem.

The methodology will use a model that simulates the hydrodynamics, water quality dynamics, and biological dynamics of an aquatic ecosystem. This model will be used in conjunction with another model that simulates the operation of a thermal power plant cooling system. By manipulating the interfaced models, the ecological effects of different combinations of siting configurations and cooling system designs can be compared.

Supporting the three major study areas are projects to develop annotated bibliographies of pertinent literature and data sets that are suitable for computer search and to characterize the cooling systems and bodies of cooling water of operating and planned electric power plants. This compiled and indexed information, in itself, will be valuable to the industry in the guidance of research and development projects, in development of more effective and efficient aquatic monitoring programs, in drafting environmental reports for regulatory agencies, and in preparation of 316a and 316b applications to permit use of once-through cooling systems.

All efforts in this study of aquatic environmental impact of power plants are being coordinated with EPRI's Water Quality Control and Heat Rejection Program in the Fossil Fuel and Advanced Systems Division. *Project Manager: Robert Goldstein*

SUPPLY

Assessment of Supply From New Technologies

In late 1976 we will begin to study the response of the metal and battery industries to the potential rapid growth in battery demand. There is a growing urgency to develop energy storage systems for use by electric utilities. Of the various technologies currently under investigation by EPRI, ERDA, and other organizations, storage batteries appear promising. A recent survey of the EEI System Planning Committee showed that batteries rate the highest priority (EPRI JOURNAL, February 1976). More federal, EPRI, and utility funds will be expended on battery R&D than on all other advanced storage technologies combined.

If battery R&D is successful, demand for batteries could increase rapidly. It is uncertain that industry will be able to expand battery output to meet the demands of the utility industry and other potential battery users on the schedule required and at competitive prices. The greatest uncertainties lie in the areas of battery materials availability and cost. Batteries are particularly sensitive to materials costs because these can amount to 50%–80% of the total cost of a battery system.

Efforts to project production costs are dominated by difficulties in projecting the quantities and prices at which raw materials will be available to battery manufacturers. Significant uncertainties also exist concerning mass production techniques for certain composite materials required by some battery systems. Under certain battery implementation scenarios, specific metals would be required in immense quantities compared with current production. For example, the use of either lead or lithium batteries (with a 10-hour storage capability) to provide 10% of new generation capacity in 1985 and beyond would require an increase of about 50% in production of these metals over current U.S. production levels.

Compounding the problem is the possible demand for other uses. In the case of lithium, immense quantities of the metal could also be required by the development of batteries for electric vehicles. The possible response of metal suppliers to increased demand is even more uncertain because metal demand can be expected to peak and then fall off as initial battery demand is fulfilled and the market settles down to normal growth and a recycling of battery materials. There is a question, therefore, of whether metal producers will be willing and able to expand production capacity on short notice at prices that will make batteries attractive to the utility industry. Additional uncertainties arise because of lead times and environmental constraints associated with construction of new mines and smelters. These lead times are likely to be from six to ten years.

The goal of the new battery study project is to identify potential materials and manufacturing bottlenecks and critical lead times at an early stage of battery development. Although the uncertainties surrounding the technologies involved will not permit a definitive analysis at this time, it is important to define the problems that may arise.

The information flowing from this study is designed to (1) ensure that if R&D is successful, there will be no surprises on the supply side; (2) assist battery developers in choosing among alternative technological approaches and designs; (3) assist in predicting equipment costs and capabilities for system expansion planning by member utilities; and (4) aid investment planning by the battery and metals industries as R&D progresses.

The study will consider four battery systems that currently are the leading contenders for near-term use in utility systems:

(1) the advanced lead-acid system, (2) the zinc-chlorine system, (3) the lithium–iron sulfide system, and (4) the sodium-sulfur (and sodium–antimony trichloride) system. Among the more critical materials likely to be studied are lead, lithium, antimony, ruthenium, zinc, graphite, stainless steel, molybdenum, and titanium.

The availability and price implications of raw material and other potential supply bottlenecks will be identified and evaluated under four or five assumed battery demand growth scenarios. The time span studied will be the period 1984–2000. Particular attention will be paid to identifying problem areas in raw material and manufacturing expansion based on history and consideration of environmental factors, risk, and capital availability. An analysis of battery pricing will be accomplished to the degree allowed by available information. This will include a description of the market environment in which the battery industry operates. For example, the interaction of the electric utility market for batteries will be considered with that of the vehicular battery market and with other competing users of advanced batteries, such as special purpose vehicles and emergency power supplies.

This work will be coordinated with hardware development efforts in EPRI's Fossil Fuel and Advanced Systems Division. Engineering input for the project will be provided by the Energy Management and Utilization Technology Department. The project is considered to be a prototype analytic framework that may eventually have application to other technologies. *Project Manager: R. J. Urbanek*

DEMAND AND CONSERVATION

Materials Processing Sector

Data Development A major barrier to the development of comprehensive and advanced forecasting models of energy usage in the industrial sector has been the lack of an adequate data base. Research Triangle Institute (RTI) recently completed Phase 1 (RP802-1) of an attempt to develop a disaggregated data base (data collected on plant level). The first phase was basically exploratory, and had it been successful, would have led to the second phase development of a data base.

Industrial energy demand models based on this type of disaggregated data base could incorporate for the first time detailed information on stocks of energy-using capital equipment by type of industrial process. Because of the engineering and technological information inherent in such data, new forecasting models could capture important structural changes in industrial energy usage patterns that result from changing relative fuel and equipment prices.

The Phase 1 work completed by RTI was aimed at removing the data barrier for ten standard industrial classification (SIC) industries at the four-digit level of detail. A critical ingredient for the success of this test project was the existence of the National Emissions Data System (NEDS), assembled by the Environmental Protection Agency (EPA) as a result of the Clean Air Act. Data residing in NEDS include fuel and process files. The fuel file includes direct fuel consumption data associated with the point sources listed in the process file. Hence, the fuel file gives information on total annual direct consumption by type of fuel at the plant level (but NEDS files do not contain information on electricity consumption). To complete the data base for analytic purposes it would be necessary to add electricity consumption information and data on quantities and prices of factor inputs as well as for plant output.

Unfortunately, problems were uncovered during Phase 1 of this project that indicated a very low probability for successful completion of Phase 2. The primary difficulties were:

- Lack of response to requests for electricity consumption data. The availability of plant-specific electricity consumption data was critical to the study. Despite repeated attempts to obtain these data through telephone and letter surveys, the responses for a sample industry (SIC 2631) were disappointing. It appears that a valid response rate of 25% would be optimistic.

- Inconsistency in the year of record for the NEDS data. For this disaggregated data base to be useful in forecasting models, it is essential that the cross section of observations be made during the same year. Moreover, an ideal data base would include time series of cross-section observations. However, the methods used for updating the NEDS file appear to have been collected over different years for specific industrial plants within an industry and sometimes even for processes within plants.

- Confidentiality of the NEDS data. EPA will not release the confidential data dealing with process operating rates to nonfederal contractors, including EPRI. Since confidentiality is imposed more stringently in some states than others, the severity of the problem varies by industry, depending on its location. For the above reasons, Phase 2 of this study will not be undertaken.

Model Development Professor Laurits R. Christensen of the University of Wisconsin has been developing models that will be used to forecast agricultural energy consumption (RP682-1). The primary focus of his effort is to provide a suitable model for forecasting the demands for electricity, petroleum products, fertilizer, machinery, structures, other purchased inputs, and labor—conditional on prices and the level of aggregate farm output. An important feature of the model is that it will simultaneously forecast all factors of production in the farm sector. By including land, capital, labor, and intermediate inputs, it will be possible to model the interactions between energy and other inputs and thus to forecast all factors in a consistent, and presumably more accurate, manner. A major portion of this project has been devoted to the development of data, as no suitable data already existed. The U.S. Department of Agriculture maintains many relevant data series, but they have required substantial reworking and further development to be suitable for the modeling work.

Technological change oriented to energy conservation in manufacturing industries is likely to have important long-run consequences to the growth of the electric utility industry. Recent developments in factor demand theory are being used in an attempt to construct economic models to explain the role of factor prices—especially those of energy—in inducing technological change related to energy use (RP683-1). Technological change in this context means the ability to achieve a given level of output with a reduced amount of input of one or more factors of production. Existing approaches to forecasting energy usage in manufacturing that employ factor demand theory are essentially static in that they fail to take into account the time lags in adjustment. Thus, the most important features of the RP683-1 modeling effort are the investigation of a process of technological change and the characterization of dynamic adjustment processes. The models are organized around a dynamic, two-stage characterization of energy consumption. One stage incorporates the substitution possibilities between aggregate factor inputs—capital, labor, energy, and intermediate goods. In the second stage, interfuel substitution between five energy types is modeled (electricity, crude oil, coal, natural gas, and refined petroleum products).

These models attempt to capture the response to changes in factor prices by reflecting the way existing capital stock is used. They also attempt to model the influence of changed energy prices and other factor prices on investment in new capital stock. *Project Manager: Larry Williams*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

CHEMICAL ENERGY CONVERSION

During the past five years, the "hydrogen economy" has been the subject of many seminars and conferences, as well as hundreds or perhaps thousands of papers. The hydrogen economy is the most notable example of a chemical energy conversion (CEC) system. CEC systems characteristically involve three steps.

▫ Conversion of thermal, electrical, or mechanical energy to chemical energy

Examples: 1. electricity + $H_2O \rightarrow H_2 + \frac{1}{2}O_2$

2. heat + $SO_3 \rightarrow SO_2 + \frac{1}{2}O_2$

3. heat + $CH_4 + H_2O \rightarrow CO + 3H_2$

▫ Storage and transportation of the chemicals

▫ Reconversion of the chemical energy to thermal, electrical, or mechanical energy (e.g., reversing the reactions in examples 1 and 2).

CEC systems are of interest for several reasons. While hydrogen-water systems are especially attractive ecologically, all CEC systems offer a highly efficient means of storing and/or transporting energy (second step above). That is, the chemicals can be stored for very long periods of time or shipped very long distances without losing energy content. In addition, CEC technologies and systems would appear to offer versatility relative to the characteristics of the primary energy source—since an infinite number of chemical reactions can be written, it is possible to match the characteristics (temperature, enthalpy, and so on) of a chemical reaction with the energy available from a variety of sources (e.g., solar, fusion, HTGR, low-grade waste heat).

The major deterrents to the widespread application of CEC systems by the utility industry are the capital costs and inefficiencies associated with the conversion and reconversion technologies (first and third steps above). For instance, because of the inefficiencies associated with the third step, the round-trip efficiency of hydrogen energy storage will be less than 60% in the best case. Thus, it is unlikely that the CEC systems will compete with other energy storage concepts for daily or even weekly cycle applications.

Program Focus

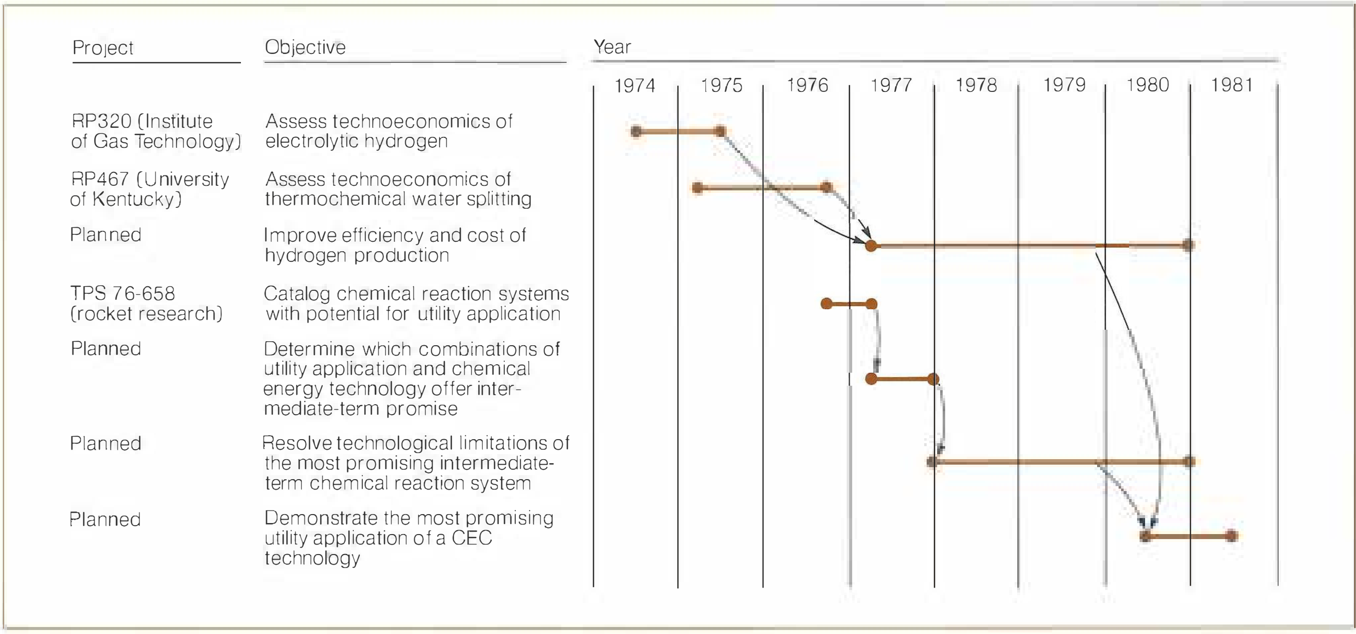
The unique advantages of compatibility with future energy sources, flexibility, and efficient low-cost storage and transmission will result in the long-range use of hydrogen and other CEC technologies. However, there will be a lack of a near-term utility application due to high energy conversion costs and efficiencies. Given these premises, EPRI's chemical energy conversion subprogram (Figure 1) methodically establishes the technoeconomics of the various CEC technologies in utility applications and then supports the efforts necessary to overcome the technological limitations of the most promising CEC concepts. The subprogram will demonstrate the most promising intermediate-term utility application of a CEC concept by 1981. The total EPRI CEC funding for 1977–1981 will be less than $3 million. This modest expenditure is consistent with the relatively long-term, speculative nature of the subprogram.

Status

The report "Utilization of Off-Peak Power to Produce Industrial Hydrogen," prepared by the Institute of Gas Technology (EPRI RP320-1), determined the feasibility of using off-peak power to generate hydrogen that could be sold to industry as a fuel or commodity. It was thought that such a concept might overcome the otherwise relatively high cost of producing hydrogen by water electrolysis. The study concluded that the use of off-peak power, with its low availability, does not significantly alter the cost of electrolytic hydrogen. Figure 2 shows the sensitivity of hydrogen cost to plant factor (availability) and power costs. It is apparent that for the GE electrolyzer system, combinations of plant factor and off-peak electric power costs that will yield hydrogen below $3/1000 scf are not likely. In addition to establishing the economics for electrolytic hydrogen, the report also provides a methodology that individual utilities can use to determine whether they have a unique situation that might allow them to profitably produce hydrogen for sale to the industrial sector. Utilities concerned with this possibility should review this final report.

A technoeconomic analysis of large-scale thermochemical production of hydrogen by the University of Kentucky es-

Figure 1 The studies and objectives that form the chemical energy subprogram and the time periods in which they will be implemented are outlined below.



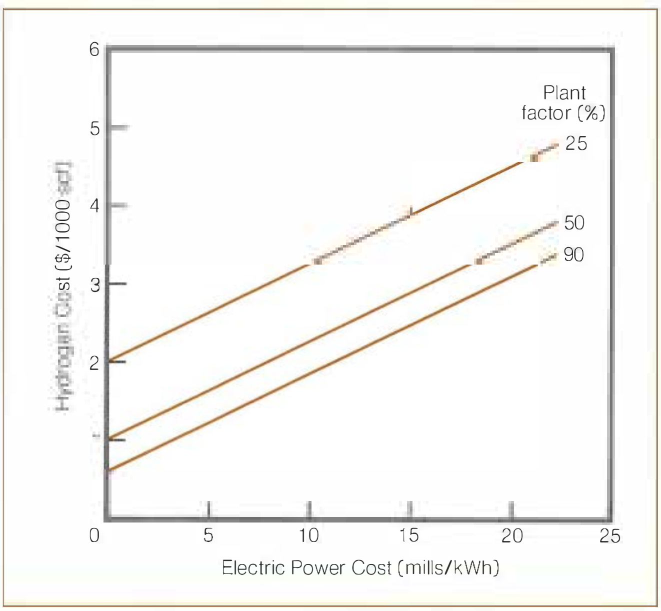


Figure 2 Hydrogen cost is directly linked to plant availability and electric power rates. This analysis for the GE electrolyzer system indicates that low hydrogen costs are not yet likely.

tablished the likely capital and operating costs and process efficiency for a large-scale plant to produce hydrogen by the thermochemical decomposition of water (RP467). Recognizing that electrolytic hydrogen might be produced at a raw-fuel-to-hydrogen efficiency of 35–40% and a $2.50/1000 scf cost, based on advanced electrolyzer technology, the comparable efficiencies and costs for a thermochemical process become important if EPRI is to properly assign priorities to its R&D efforts. This three-phase project reviewed all thermochemical water-splitting cycles for which data were available, selected a four-step sulfur cycle (Schulten-methanol) for detailed analysis, and developed a thermochemical plant design based on that cycle and a very high temperature reactor (VHTR) heat input of 3345 MWt at 1600°F. The resultant efficiency and economics for the hydrogen produced were essentially the same as those projected for advanced electrolysis.

Given the nearly equivalent efficiencies and economics for advanced electrolysis and thermochemical approaches, no further near-term efforts are anticipated in the more speculative thermochemical area. However, a project to advance electrolyzer state of the art will be initiated in 1977.

Several efforts abroad and in the U.S. (ERDA) are assessing and developing other chemical energy systems, including H_2SO_4—H_2O; CH_4 reformation; SO_2–SO_3; and cyclohexane-benzene. Since each chemical reaction combination involves a specific temperature of energy input and output, an electric utility application analysis requires a complex matching of the heat characteristic of both the energy source and the end use with the chemical reaction cycle. Current CEC efforts have focused on CEC technology assessment and development with little attention to application analysis. To simplify the required application analysis, all CEC reactions of potential utility interest will be cataloged in TPS 76-658. This catalog will subsequently serve as a design data base that can be matched against the intermediate- and long-range utility applications. The planning study will be completed early in 1977 and the application analysis will be started simultaneously.

Outlook

While there are many interesting CEC-related concepts that might be beneficial to the utility industry, none of them is likely to be technoeconomically viable in the near-to-intermediate term. However, in the longer term, as fossil energy sources become scarce and the utilities must rely on fission, solar, and fusion sources, hydrogen and other CEC systems will likely be an efficient and cost-effective means for coupling the energy source with the end use via long-term storage or long-distance transmission. In the meantime, it will be necessary to develop the more promising technologies and seek out the nearer-term applications that will bridge the gap between today's technology and tomorrow's need. *Program Manager: Arnold Fickett*

WASTE HEAT MANAGEMENT

Virtually all discussions of research, development, and design activities related to power plant systems and components contain the following objectives: reduced capital cost, increased generation efficiency, and acceptable environmental impact. These objectives are often in conflict. Heat rejection systems represent a significant fraction of plant capital costs, have a dominant effect on plant heat rate, and constitute one of the major sources of the plant's impact on its environment. As such, they exemplify the conflict, and a balanced research program must address all facets of the problem. This report will focus on the environmental aspects.

The thermodynamic laws governing thermal power generation require that heat be rejected from the power plant. At efficiency levels achievable with current and foreseeable technologies, this rejected heat amounts to one-half–two-thirds of the energy contained in the fuel. The lower the temperature at which this heat rejection is achieved, the greater the efficiency of the power generation; the more effective the heat transfer processes by which the heat is transferred from the plant to the environment, the smaller and less costly are the cooling systems. Therefore, from a cost and efficiency standpoint, heat rejection to water rather than to air, or to wet-bulb temperatures rather than to dry-bulb temperatures, is the preferred technology.

Physical Effects Versus Environmental Impacts

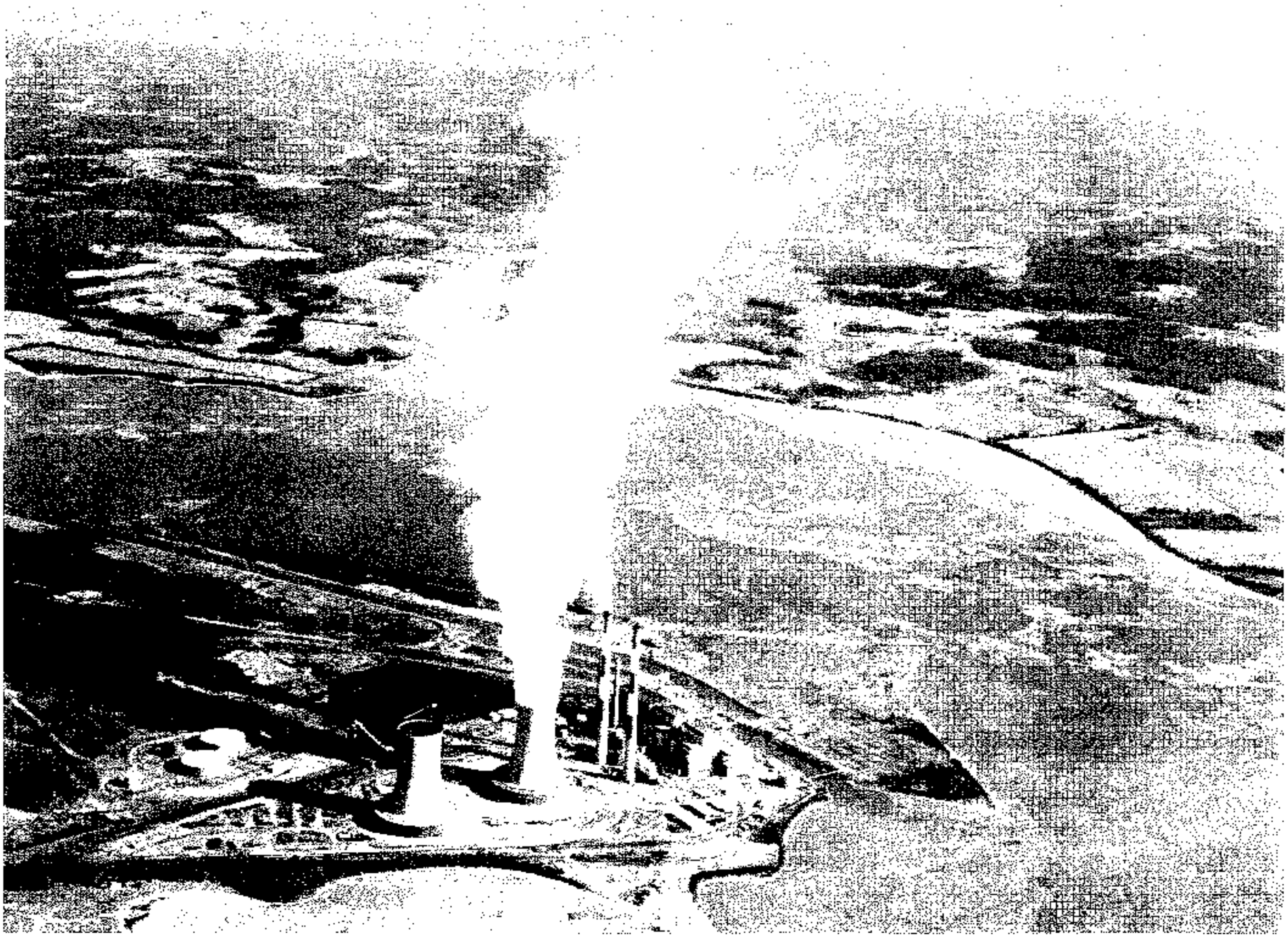
The localized injection of relatively large quantities of heat into the environment must result in some local disturbance of the physical condition of the environment, even though the effect is negligible in a global heat balance. The thermal discharge itself will be manifested as an increase in the local temperature of the air or the water, or an increase in the evaporation rate and an associate increase in local humidity, depending on the particular cooling system selected. The need for maintenance and cleaning of the cooling equipment may result in the use and eventual discharge of biocidal, anticorrosive, or antiscaling chemical species. The physical processes by which the cooling is achieved may result in the concentration of source water constituents through evaporation and their dispersion to the land and atmosphere through splash, carryover, and drift.

The extent to which these physical occurrences constitute harmful or undesirable effects on the local environment and ecosystems must be determined from meteorological, biological, and ecological research. Such studies are under the purview of the Environmental Assessment Department of the Energy Analysis and Environment (EA&E) Division, and those related to aquatic ecosystems are described in the EA&E status report in this issue. The goal and responsibility of the FFAS Division's environmentally directed activities are to predict and, if necessary, to reduce the physical manifestation of power plant cooling.

Research Emphasis

The Federal Water Pollution Control Act of 1972 and subsequent effluent limitations, guidelines, and standards in the Steam-Electric Power Generating Point Source Category, New Source Performance Standards, prohibit the discharge of heat to waterways from main plant condensers, except in cold-side blowdown from recirculating cooling systems. While provisions exist for seeking exemptions, the increased use of closed-cycle cooling systems (particularly cooling towers) is to be expected. This has the effect of transferring the localized physical manifestation of the thermal discharge from the waterway to the atmosphere in the form of warm, moist (and sometimes visible) plumes and potentially to the surrounding land in the form of dispersed liquid or drift droplets carried from the tower. The potential environmental impact of these plumes could include local weather modifications, such as increased fogging, cloudiness, or precipitation; possible ground level icing of roads, structures, and vegetation; and the dispersal of salt, concentrated in the drift droplets. A major project, jointly sponsored by EPRI, ERDA, EPA, and the state of Maryland, should provide a sound basis for predicting and evaluating both the physical effects and

Figure 3 This 600-MWe oil-fired cycling plant at Chalk Point, Maryland, is the site of studies that will provide data on the behavior of cooling tower plumes and on possible environmental impacts. *Photo courtesy Applied Physics Laboratory, Johns Hopkins University.*



the environmental impacts of plumes that drift from cooling towers.

Chalk Point Cooling Tower Project

Figure 3 is an aerial view of the test site at the Potomac Electric Power Co. Chalk Point plant located at the confluence of the Patuxent River and Swanson's Creek in Prince Georges County, Maryland. The tower from which the visible plume is rising cools a 600-MWe, oil-fired cycling plant. Brackish make-up water for the tower is taken from the river at an annual average salt concentration of about 7000 ppm. Average drift salinity is approximately 14,000 ppm. The surrounding countryside is primarily agricultural, and the potential impact of saline drift on the local tobacco crop is of concern.

The development of analytic and numeric methods for predicting the behavior of drift and vapor plumes has been the subject of intensive effort by numerous investigators for several years. As a result, a number of models have been proposed. The objective of the project is to provide comprehensive, quality data against which these models can be compared, validated, and improved.

The measurements involve (1) plant and tower operating conditions; (2) tower emission characterization tests, including in-tower velocity, temperature, and humidity profiles and drift emission mass and droplet size distribution; (3) airborne in-plume measurements of temperature, humidity, and drift concentration; (4) photographic recording of the visible plumes; (5) airborne and ground-level salt concentration and deposition rates; and (6) ambient meteorologic data from aircraft, sondes, and an on-site meteorologic tower. The link between the physical occurrences and the environmental effects will be provided by observations of botanical and agronomic test pilots from which pre- and postoperational data on salinity effects and drift-induced injury will be generated and evaluated.

Thermal-Hydraulic Plumes

The major impediment to the use of once-through cooling systems is the environmental impact imposed by the entrapment and entrainment of organisms and the discharge of a heated water plume. The major objective of EPRI's program in this area is to provide utilities with support when they apply for 316a exemptions under the Federal Water Pollution Control Act of 1972 and to facilitate the maximum environmentally acceptable use of once-through cooling. As in the case of tower plumes, numerous predictive models have been developed. None of these, however, is generally applicable; nor is it clear how to choose the best model for any given situation. Each of the models normally must be calibrated with site-specific data in order to give acceptable results. In general, however, our ability to predict plume temperature profiles and dimensions exceeds in accuracy our ability to use these results in the prediction of the accompanying ecological effects.

The EPRI program planned in this area will contain several elements: (1) effects studies in conjunction with the Environmental Assessment Department (EA&E Division) to determine the impact of the synergistic thermal, physical, and chemical effects of once-through cooling systems on aquatic organisms; (2) the development of performance-related guidelines for the design of intake and discharge structures; (3) the characterization of available water resources suitable for use with once-through cooling; (4) the development of guidelines for the use of physical models, including the development of appropriate scaling laws and furthering the understanding of the use of distorted models; (5) the extension of the existing data base to include dynamic effects, end effects, and seasonal and diurnal variations in plume characteristics and the development of comprehensive test procedures for pre- and postsiting plume characterization that can be generalized; (6) continued work on model comparison and verification, leading to general recommendations on the suitability of proposed models for particular applications.

Chemical Discharges

The major chemical discharge from power plant cooling systems is the chlorine used for control of biofouling in the condensers and intake-discharge structures of once-through cooling systems. Increasingly stringent EPA regulations on allowable chlorine discharges are anticipated. A three-pronged approach will be conducted in this area: (1) the determination of minimum chlorine dosage requirements to maintain effective biofouling control; (2) the development of dechlorination procedures; and (3) the study of alternatives to chlorination.

A project currently under way is evaluating the use of ozonation as an alternative to chlorination. Ozonation has been demonstrated to be an effective means for the control of biofouling in certain specialized applications. The major uncertainties to be resolved in the application of this technology to power plants include dosage requirements, cost-effective contractor design, and residual toxicity effects. Tasks will include parallel tests of untreated, chlorinated, and ozonated condensers to determine the dosage requirements for maintaining equivalent performance under a variety of dosage schedules, as well as an engineering design study and cost analysis of several promising contractor designs. A parallel study will be carried out by ERDA's Division of Biological and Environmental Research to define potential residual toxicity effects. A coordinated effort with EPRI's Environmental Assessment Department is planned for studies on minimum dosage requirements and effects associated with other alternatives to chlorination (including bromine chloride and chlorine dioxide). *Program Manager: John Maulbetsch*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

SUBSTATION COMPONENTS

A major cost factor in the production of power transformers and other substation equipment has been the extra insulation that must be built in to withstand overvoltages due to lightning or switching surges. In the past 20 years, surge arrester manufacturers have made great strides toward reducing this cost. As a result, almost all users purchase equipment with reduced basic impulse insulation levels (BILs) at a cost savings. A new laboratory development may provide the protection necessary to extend this reduction to about its logical limit. Properly treated zinc oxide is a semiconductor with some remarkable characteristics. It has almost a constant voltage drop over a current range spanning five orders of magnitude. It can be made to absorb more energy per unit volume than silicon carbide, which is now being used in surge arresters. It can also be formed in large blocks, enabling its use in practical arrester designs.

EPRI feels this development is so essential that two complementary efforts have been launched. McGraw-Edison Co., in conjunction with Marquette University, has been conducting basic studies to determine the effects of various compositions and processing variables. In addition to statistical analysis of experimental results, scanning electron microscope and X-ray defraction analyses are being used as diagnostic tools.

Westinghouse Electric Corp. is continuing an effort that it launched two years ago in an attempt to increase the energy absorption capability of zinc oxide blocks, while retaining the highly nonlinear volt-ampere characteristic. Westinghouse is also investigating formulation and processing variables in a production-type setting. The objective of these projects is to produce a gapless transmission surge arrester that will limit overvoltages to 1.5 per unit of normal line-to-ground voltage. We expect to reach this goal in 1979.

The design of support insulators in gas-insulated equipment is made difficult by the requirement for small size (thus short creepage paths) and the difference in dielectric constant between most solid insulation and gas. Researchers at I-T-E Imperial Corp. reasoned that if a polymer insulating material could be foamed with SF_6 gas, the resultant material would have a dielectric constant closer to that of the gas alone. However, normal foaming techniques do not work with the epoxy compounds commonly used for insulation. An effective foaming technique was found by loading a molecular sieve with SF_6 gas, mixing it into the uncured epoxy, and using heat to liberate the gas and cure the epoxy.

Molecular sieves are crystalline alumina silicates, commonly called zeolites. The crystal structures have large internal or inner crystalline surface areas, which accounts for their gas-absorption capability. The material is supplied as a fine powder so that it disperses evenly in the epoxy and is inert.

The project is seeking to determine the effective life of the material. "End of life" can be defined as occurring when enough gas has been diffused out of the material to degrade its insulating qualities. Sophisticated techniques must be employed to determine gas diffusion rates in a reasonable time. These rates can then be extrapolated to 30 years. Instrumental neutron activation analysis was chosen because it is nondestructive. After the SF_6 concentration is determined, the sample can be artificially aged, and the gas concentration can be redetermined at various stages.

An attempt to obtain reproducible short-term dielectric failures will also be made so that Arrhenius projections of life can be calculated. Techniques for loading molecular sieves and foaming the epoxies have been developed, and preliminary SF_6 concentration and pressure measurements have been made. Samples have been produced and life tests begun. The results of this work will determine whether the material is suitable for the applications contemplated.

Recognizing the need for cost-effective transmission-voltage-level reactor and capacitor switches, Bonneville Power Administration (BPA) and EPRI are jointly sponsoring such a development. The goal is a line of switches rated 242, 362, 550, and 800 kV, with a continuous and interrupting capability of 600 A for capacitive and reactive loads. The first step (now in progress) is the development of a 242-kV, single-break, SF_6 interrupter module. The three interruption strat-

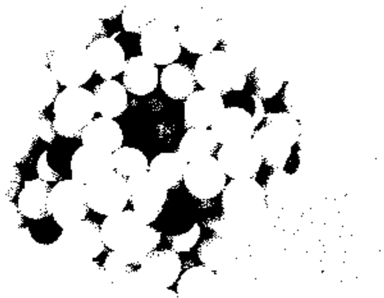


Figure 1 Model of molecular sieve crystal, illustrating the open structure and inner crystalline surface area.

egies being investigated are plain break in SF_6, puffer, and arc-generated gas blast. A model interrupter has been built and tests are being conducted. It is expected that resistors will be used for both closing and opening to limit overvoltages and inrush currents.

In 1977 the contractor, Westinghouse, will build a 550-kV, three-phase prototype, conduct laboratory tests, and deliver it to BPA. BPA will then conduct field tests and install the prototype to gain operating experience.

System volts-amperes-resistors (VAR) control is an increasingly important subject as more generating capacity is located at a distance from the load center. The important question of how to provide voltage support at the load center is being addressed by many utilities. Load flow and system stability studies of Minnesota Power & Light Co. have identified a location on its 230-kV transmission system where high-speed VAR control voltage support would be advantageous. Stability studies were performed for two cases. One was the loss of key generation; the other study simulated the starting of large motors at a taconite mill. In both cases it was demonstrated that the high-speed response of a static VAR controller was effective in reducing bus voltage swings, thus reducing the requirement for installed capacitors.

The basic VAR control system being manufactured by Westinghouse for this application is a two-step, switched, capacitor bank in parallel with thyristor-switched, air-core reactors. Vernier control of the reactance can be achieved by varying the firing angle of the thyristors. Bus voltage is evaluated each half cycle, and an appropriate adjustment is made in the thyristor firing angle. Control response time is equal to or less than one cycle. Other possible control strategies are being investigated to see if they offer any advantages over voltage control.

The generation and suppression of harmonic currents is also being addressed in this project. While studies show that the harmonics generated are not severe, there are certain system configurations that may be tuned to these harmonics. For this reason, part of the shunt capacitance will be in a harmonic filter configuration.

Installations of similar hardware have been made for flicker control of arc furnaces. In that case, the control is open loop, based on the VAR demand of the arc furnace. It is used only to compensate for the VAR demand of the load and not to correct for bus voltage variations.

The use of gas-insulated equipment in substations is increasing at an exponential rate. Two threats to this type of equipment are moisture and loss of gas. The gas itself is expensive and leaks should be detected as early as possible. Further, if gas can leak out, then moisture can leak in. What is needed is an inexpensive, full-time leak and moisture detector. Nucleonic Data Systems has developed a detector that offers a cost-effective solution. Infrared light is passed through the gas, and the SF_6 density and water vapor density are detected by measuring the absorption of certain wavelengths. This technique has been used successfully in the space effort and now may solve a utility problem.

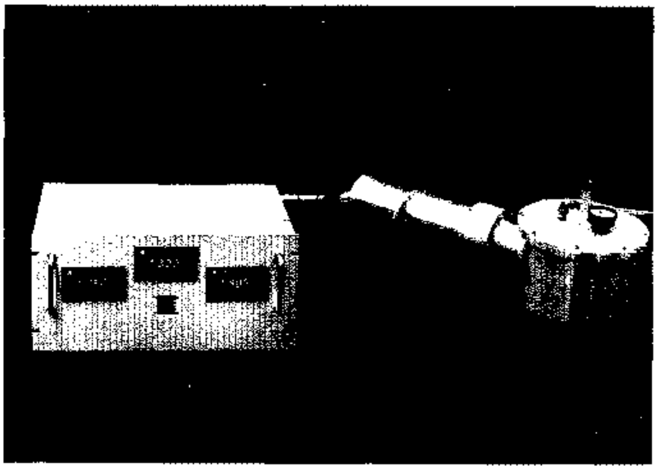
In practice, we envision one detector head on each gas chamber. There may be tens of these in a particular substation. All the detector heads will then feed into one scanner-processor. This device will indicate SF_6 density, rate of change of SF_6 density, and water vapor density. Readings will be made every few minutes around the clock, and an alarm will sound if preset limits are reached, thus reducing to a minimum the time an out-of-tolerance condition is allowed to exist.

Large transmission substations sometimes look like a forest of insulators. But there are many more insulators hidden within various pieces of equipment. Until now, no one has developed a cost-effective material that is superior to porcelain for most of these insulators. However, two very important developments with similar names will soon produce insulators that are equal or superior to porcelain and at a reduced cost. Further, the new materials will require only about one-tenth of the energy now used to process porcelain.

Polymer-impregnated concrete (PIC) is concrete that is mixed and cast in much the same way as ordinary structural concrete. By proper control of the process, pore size and distribution can be optimized. The cured concrete is then thoroughly dried and vacuum impregnated with a monomer, which is polymerized and cured. This process is in an advanced stage of development.

However, it appears that the second contender, polymer

Figure 2 Infrared detector head connected to test chamber (right). SF_6 density, rate of change of SF_6 density, and water vapor density can be read on scanner-processor (left).



concrete (PC), may offer processing advantages without sacrificing performance. The contractor, Westinghouse, is now concentrating its effort on this material. PC is a mixture of aggregate (sand, gravel, ground-scrap porcelain, fibers, and so on) and polymers, such as methyl methacrylate. The polymer content may only be less than 12% by weight. The material can then be cast in air and cured at a reasonable temperature. Efforts are now being expended toward improving the strength, creep, dielectric, and weathering properties.

Significant Projects Completed

The Phoenix Electric Corp. of Boston has been developing a current-limiting conductor (CLC). This project is now complete and the final report is available (EPRI EL286). The theory of the CLC has been developed and confirmed by experiments. The principle of the CLC is based on a linearly extended solenoid. Its inductance increases as the air gap between the armature and the core is reduced by short-circuit current.

Design formulas have been developed. The nonlinear interaction of the electric circuit and the magnetic-mechanical system was analyzed. Both steady-state and transient solutions were obtained. Analysis suggested that a switched resistor be added to the circuit. Commutation of current to the resistor was explored. A cost analysis indicated that the CLC cost reduction of 90% can be achieved by the inclusion of the resistor for a given performance requirement.

Fractional CLC modules were built and tested to confirm theory. Costs were reported and extended to full-scale 5-kV and 15-kV substation devices. *Project Manager: Richard Kennon*

Alfred Kahn Breaks Tradition

The chairman of New York's Public Service Commission, a member of EPRI's Advisory Council, refuses to be bound by tradition in his role as a regulator. ▫ An EPRI interview

"I think it's terribly important that the electric companies and EPRI be aware, every moment, that the dollars they're spending are not theirs, but the ratepayers' dollars. And that's the interest I'm supposed to represent," said Alfred Kahn with characteristic intensity.

Kahn is chairman of the New York Public Service Commission (PSC) and an articulate member of EPRI's Advisory Council. As the first professional economist to head a major utility commission in the United States and as an outspoken advocate of regulatory reform, Kahn is the recognized dean of utility commissioners. An academic dean as well, he is now on leave from Cornell University's College of Arts and Sciences, where he was also a professor of economics.

Part of his reason for being on the Advisory Council, says Kahn, is "to keep an eye on things"—that is, to see how the ratepayers' dollars are being spent on electric utility research and development.

Kahn has no quarrel with the composition of the Council, which he considers to have "sufficient representation," except for a consumer advocate. But until the formation earlier this year of the four working committees, Kahn had "a good deal of uncertainty about the Council's effectiveness." He and other members of the Power Sources and Uses Committee, Kahn points out, have proposed to EPRI management that the Institute spend less of its resources on long-range research and more on projects that have "a shorter-term payout." The committee has been pressing for more work "on immediate, practical, industrywide problems, such as reliability of generating plants," he says. We should look to ERDA to sponsor costly, long-range R&D, Kahn argues.

"EPRI is a very professional organization, and I have no reason to doubt Chauncey Starr's dedication to good research," says Kahn. However, Council members are "trying to develop a forum in which we get a better representation of opposing viewpoints." He cites what he sees as "a tendency of the industry and of EPRI to be supply-oriented." Kahn notes that he and others on the Council have pushed for more research on conservation and efficiency. And he credits this pressure with partially influencing EPRI to include locations in northern climates in the U.S. in its residential heat pump test program.

As a utility regulator (there are 7 regulators on EPRI's 24-member Advisory Council), Kahn says his "only job is to regulate utility monopolies in order to protect the interest of ratepayers." But he recognizes, "In practice, some commissioners have a tendency to identify with the people they're supposed to regulate. There are a lot of reasons for this tendency," Kahn continues, "that have nothing to do with the obvious ones of venality, corruption, or expectation of getting a job with a regulated company after you leave the commission. It is something we must all, in varying degrees, resist."

Kahn adds, "I don't want to be understood as having made the self-serving statement that we are all harsh, effective scourges of the utility industry. But in some degree, that's our function."

Kahn says he plans to return to Cornell and his economics professorship when his six-year term with the New York PSC ends in 1980.

The regulatory community, with prodding from Kahn, has begun reforming its traditional approach to electric utility regulation. It was NARUC, prompted by the resolution he cosponsored, Kahn notes, that requested EPRI and the Edison Electric Institute to undertake the Utility Rate Design Study. And in the area of R&D, Kahn says commissions have begun urging utilities "to develop a research consciousness and begin to spend money on research."

As for the utility industry's past performance in forecasting, Kahn criticizes that effort as having been "little more than the application of a straight-line ruler to a graph of semilog paper." Again, as a result of commission pressure, more utility companies are developing their own staff capability or are seeking the

I find the reason I have such enthusiasm about my job is that I'm looking at things almost constantly in a way that most regulators find nontraditional.

advice of consulting firms in formulating their projections of customer demand, need for generating capacity, new technologies, and the like. Part of EPRI's program is to develop analytic forecasting methods, as well as to project the structure of demand and supply. The purpose is to better define EPRI's R&D targets and priorities, and, in addition, to provide insight into forecasting methods for individual utilities.

In New York over the past few years, Kahn tells us, the PSC has been pressing the seven major utilities of the state power pool to plan on a statewide rather than an individual basis. It has been proposed that the siting, construction, and operation of all privately owned generating plants in the state be handled by a single company. Kahn points out that such integrated long-range planning could produce several advantages: costs and environmental impact would be minimized, and the single company would be justified in recruiting the necessary staff to handle its planning.

Even now, Kahn says, "Increasingly, we push the seven utilities to come up with an integrated pooling forecast of demand, of supply availability, and projected plant additions over a 15-year period. Also, we've got them to include tentative preselection of plant sites and to identify major transmission corridors." These plans, which are subject to revision, allow for improved land-use planning, Kahn notes.

Evaluating company efficiency has always been a difficult task for regulators, some of whom are now using the relatively new technique of management audit. "Management audit is not bookkeeping or routine checking of the accuracy of records," explains Kahn. "Rather it is a study of the organization, policies, and operations of a company with a view to assessing efficiency in a broad sense."

Kahn says that commissions also have begun to develop statistical methods, which they either apply or get the companies to use, to measure changes in productivity over time. Items measured include output per man-hour, per dollar

The utility industry's past performance in forecasting has been little more than the application of a straight-line ruler to a graph of semilog paper.

of capital, and per bundle of input.

Because of the "inescapable tendency of regulated monopolies to be cost-plus in their rate pricing, along with the difficulty regulators have in examining their costs, and in the absence of competition," Kahn says, "there is always the danger that these monopolies will be bureaucratic, unenterprising, and will not press vigorously for efficiency."

Management audits and productivity measurements are two methods for nudging utilities toward efficiency. But the most effective stimulus, according to Kahn, is "regulatory lag"—the delay in the time between rate changes. This situation may occur when, for a time, a utility will be squeezed if its costs go up before it gets a rate correction. Or, for a time, the company will benefit from its last rate increase and earn high profits if it achieves increased efficiency. "It's in the space between rate changes," says Kahn, "that a company has the incentive to do better."

Kahn is deeply involved in the controversy over whether rates should be based on fully allocated historical costs or on long-range incremental costs and is an outspoken advocate of the latter. Traditionally, utilities have favored the historical-cost approach, in which the costs of all plants, old and new, are allocated over the total system output, yielding a single average figure for plant cost per kilowatthour.

According to incremental-cost theory, on the other hand, the price of each kilowatthour should be based directly on its actual current cost. Following this rationale, the plant-cost increment is higher for electricity generated at a new plant (at today's inflated construction costs and bond interest rates), and all customers should be confronted with that true cost in making their purchase or conservation decisions. Price thus signals the cost incurred by society in generating another kilowatthour—or what society saves by not generating it.

Also, electricity demand is cyclical, and the generating cost is greater at peak periods (using expensive fuels) than off peak. The peak price should therefore be greater, according to the incremental-cost advocates, or there will be no price-signaled incentive for the consumer to use less of the costly electricity and more of the cheaper electricity.

There is always the danger that these monopolies will be bureaucratic, unenterprising, and will not press vigorously for efficiency.

So long as the higher costs of greater capacity or load are not reflected in higher prices for that capacity or load, the utility is charging its customers less than cost, the theory continues. What's worse, the customer is getting erroneous signals and cannot make sound economic choices in the amount and timing of his electricity use.

"If you move to current- or incremental-cost pricing of electricity," Kahn explains, "you clearly must have time-of-consumption pricing—prices that will vary by hour of the day and by season of the year." He continues, "If you use the traditional method of just averaging costs, as has usually been done (a kilowatthour is a kilowatthour), you get no differentiation."

Kahn would like to see commissions move immediately toward the position—which he calls intermediate—that says: "Never mind whether you want to go to incremental-cost pricing or stick with historical-average pricing. You should at least have time-of-consumption rates; rates that differ, reflecting the fact that, even historically, the costs of installing more capacity should not be put on people who consume off peak. They are not responsible for construction of that capacity."

"It is indisputable that the costs imposed on a system, if only the generating costs," Kahn stresses, "are different when you consume at peak on a hot summer day or you consume in the middle of the night—so that truly cost-based rates cannot avoid varying by time of consumption, logically."

Kahn sees "a strong inclination in the utility industry to resist methods of pricing that discourage growth of demand on peak, and in turn discourage growth of capacity." The reasons for this, he says, "are partly the promotional supply orientation of the industry and partly the fact that regulated utilities make their profits as a return on their rate base, that is to say, on their invested capital. And, therefore, it is in their interest to have as big an investment as possible.

"How do you have a big investment? I'm not saying it's a conscious policy, but you charge below the cost at the time of system peak," Kahn explains. "That encourages growth of demand which you can satisfy only by installing more capacity. You then go to the commission and say: 'Look, I have to install this capacity because the demand is great at that time.' The capacity goes in; it goes into your rate base; you get a return on that rate base. And as long as that return is higher than the price you have to pay for your capital, you make profits."

Kahn emphasizes that he is "not trying to discourage growth of energy demand. Energy is good and socially desirable. I want to discourage *inefficient* growth of energy demand, and I'm defining inefficiency very precisely as growth of demand that gives people fewer satisfactions than it adds cost to society. And the only measure of that is incremental."

Kahn looks favorably on the setting up of a research organization that would concentrate on regulatory issues. "I have a lot of skepticism about whether EPRI should be the one to do it," he says. "EPRI has a board of directors that is made up of utility executives," Kahn notes; adding, "to the exent that they have an influence, I don't want them running regulatory research."

"The delicacy of research on regulatory matters, being controversial and so closely related to public policy, dictates that it be handled by a university," Kahn feels. "Universities have strong traditions of intellectual independence." He believes that a university-based institute with an advisory board representing the utilities, the regulators, and perhaps EPRI could properly and effectively perform this function. He reports that more than a score of universities have shown an interest in such an institute.

Kahn, who attacks a job, not merely approaches it, revels in his work as a regulator. "I find the reason I have such enthusiasm about it," he relates, "is that I'm looking at things almost constantly in a way that most regulators find nontraditional." He sees a "uniqueness in having an economist as chairman of a major regulatory commission"—and especially an economist who has written extensively "on pricing, on environmentalism, on economic growth."

Says Kahn, "What I love about my job is that it constantly presents me with new problems that call for new ideas. Recently, I came up with an idea on regulating water companies—not very profound, but nontraditional. I found fellow commissioners who were encountering the same problem and didn't know what to do about it. I sent them copies of what I had written on the subject, and it really was exciting to see that a very simple kit of economic ideas for looking at things could solve the problem."

This illustration points up Kahn's approach to his work as an economist-regulator. "Providing perspectives that are highly relevant today in a society that has suddenly become aware of economic problems is what economics is all about," he says. Moreover, "resource scarcity and conservation are what we economists have been talking about all along."

Kahn admits, "Having been a dean for five years—the lowest man on the totem pole, really—suddenly to become a boss in a hierarchical situation in which it's hard to get people to argue with you, is heady stuff."

Alfred E. Kahn brought enthusiasm and unique credentials to the task when he was appointed chairman of the New York State Public Service Commission in 1974.

He is one of the few professional economists to head a major utility regulatory commission, which must deal with a maze of complex economic issues. His two-volume *The Economics of Regulation*, completed in 1971, is looked on as the authoritative work in the field.

Kahn took leave from a 27-year career at Cornell University, where he was dean of the College of Arts and Sciences and a professor of economics, when he was tapped for the chairmanship of the New York PSC. He plans to return to Cornell at the end of his six-year term.

Aside from his commission activities, for which he is known as an innovator, Kahn is a member of the Environmental Advisory Committee of the Federal Energy Administration, the Board of Directors of the New York State Energy Research and Development Authority, the Executive Committee of the National Association of Regulatory Utility Commissioners; and is chairman of NARUC's Committee on Electrical and Nuclear Energy. In addition to being a member of EPRI's Advisory Council, he is on the project committee of the EPRI/EEI Electric Utility Rate Design Study.

Kahn has testified extensively before the Federal Power Commission on regulation of the field price of natural gas, and before several Congressional committees on such matters as financial problems of electric utility companies, electricity rate structure, the energy problem, and the role of market power in inflation. He has served as a member of the National Academy of Sciences Advisory Review Committee on Sulfur Dioxide Emissions, was on the senior staff of the President's Council of Economic Advisors (1955–57), was a special consultant with National Economic Research Associates (1961–74), and has consulted with the U.S. Foreign Agriculture Service, Federal Trade Commission, Ford Foundation, and the government of Algeria.

Kahn earned a doctorate in economics from Yale in 1942, served in the U.S. Army, worked in the Antitrust Division of the Justice Department, and on the Twentieth Century Fund studies of cartels and monopoly before reentering academic life in 1947.

International Electric Research Exchange

Costly and time-consuming duplication of effort can be reduced through the international exchange of information on electric power technology. IERE provides the mechanism for that exchange.

An encouraging and increasingly productive spirit of cooperation now exists among many of the industrial nations of the world that are coping with various kinds of energy problems. The international exchange of information on energy technology through numerous channels is proving beneficial to all who are involved.

One of the best examples of cooperation is that among the electric utility industries of 14 nations through the International Electric Research Exchange (IERE).

Founded in 1969, IERE is an organization whose objective is to promote the international exchange of research information relating to the electric utility industry. Its by-laws put it this way: The organization "shall provide a means by which the electric power industries in the various countries can share information on electric power research in the interest of providing and maintaining adequate and economical supplies of electricity."

Shift to moderate growth

The electric utility industries in European countries are represented in IERE through the Union Internationale des Producteurs et Distributeurs de l'Energie Electrique (UNIPEDE); Japan, through its IERE Council; Canada, through the Canadian Electrical Association; and the United States, through EPRI. (U.S. representation in IERE, originally through the Edison Electric Institute, was transferred to EPRI in 1974.) Dr. Chauncey Starr, EPRI president, serves as the principal U.S. representative, with Milton Levenson, director of EPRI's Nuclear Power Division, as the alternate representative.

EPRI was host for the eighth annual meeting of IERE in Palo Alto, September 14–16.

What benefits accrue from the ongoing international information exchange of IERE? Dr. Naohei Yamada, director of Japan's Central Research Institute of the Electric Power Industry (CRIEPI), alluded to them in the foreword to his remarks, "R&D in the Electric Utility Industry in Japan." Dr. Yamada, the principal IERE representative for Japan, told the delegates:

"After the oil embargo by Arab countries in 1973, Japanese society and its economy shifted from a higher-growth-oriented structure to a more stable and moderate economic expansion. However, the electric utility industry of Japan is now struggling with difficult problems it has never before faced in its long history. These concern various aspects of power plant siting, environmental protection and conservation, higher fuel costs, stagnant electric power demands, and investment financing.

"Major emphasis of the research activities is placed on nuclear power, a promising and feasible substitute for oil, and on the technologies for environmental protection and conservation, which are required to cope with the growing concern of the general public. Research efforts continue in the fields of bulk power transmission, development of new forms of energy and energy conservation measures, improved operation and maintenance of conventional steam power generating plants, and aseismic considerations for power facilities and structures.

Common concerns

"It is very likely that the technical research subjects mentioned in the preceding paragraphs are more or less common to the electric utility industry in other parts of the world, and it follows from this that closer international cooperation and collaboration on technology

research and development will be vital for the advancement of electric utility engineering and for the solution of common industry problems and difficulties.

"In this respect, nothing can give greater pleasure than the fact that the vigorous activities of IERE promote more positive and freer exchange of technology information between the member countries year after year and obtain excellent and significant results."

Dr. M. E. A. Hermans of the Netherlands, deputy director of KEMA and chairman of the UNIPEDE research coordination organization (CORECH), presented a general review of activities in the UNIPEDE countries.

"The 'oil crisis' and the economic recession have had a profound influence on the electric industry," he said. "Its steady growth and assured supplies of fuel can no longer be taken as a firm basis for policy.

"The oil crisis at the end of 1974 was reflected in a decrease in the growth of total electricity consumption in all UNIPEDE countries except the Netherlands, where it is mainly the growth of the industrial use of electricity that has decreased this year; further, except for Belgium, there has been a corresponding decrease in the growth of the domestic use of electricity in all UNIPEDE countries.

"The economic recession seems to have as its consequence the attainment of negative growth figures for total electricity consumption, the result of an even larger decrease in the growth of industrial consumption, while the domestic consumption seems to approach its former growth figures.

"The uncertainties with respect to energy supplies instigated by the oil crisis resulted in increased attention by governments to energy problems, attempts at diversification of energy sources, and development efforts for unconventional sources of energy.

"In many countries, energy programs have been proposed by governments, while, at the same time, international contacts on energy matters have multiplied."

Alternative energy sources

John Syrett of the United Kingdom's Central Electricity Generating Board reported to the delegates that "since 1973 there has been a renewed interest in the possibility of reducing oil consumption by providing a greater proportion of our energy requirements from natural energy sources." He presented a paper on the subject on behalf of Dr. D. J. Littler, controller of research for CEGB.

"Water has always provided a significant contribution to man's energy needs, but now that many of the sites for economic hydroelectric generation have been exploited, interest has turned to harnessing other natural forms of energy —the sun (both directly through heat or light and indirectly through the secondary forms of energy that it generates, such as wind and waves), the tides, and geothermal heat from the earth.

"This interest, of course, is not new," Syrett explained. "It is sometimes forgotten that only 20 to 30 years ago there was a similar concern about the exhaustion of fossil fuel reserves, which led to a revival of interest in these renewable energy resources."

Syrett explained that at that time new discoveries of oil deposits led to lower oil prices, and the large costs associated with development of the natural energy sources caused a decline in interest.

In his concluding remarks, Syrett explained that "because of the difficulties of competing economically with fossil fuels and nuclear energy, environmental impact, fluctuating supply, and the long

lead time needed for significant commercial development, these alternative sources cannot make a large contribution by the end of the century."

Broader concerns

Other papers presented at the IERE meeting covered nuclear power programs in the various countries, problems relating to the growth of power systems, environmental concerns, research problems in the breeder reactor development programs of the UNIPEDE countries, and all phases of electric energy research in the U.S.

The international information exchange generated by IERE over the past eight years is substantial. It not only occurs at the annual meetings, but continues throughout the year, particularly among technical representatives of member companies. Because of this, IERE is altering the format of future annual meetings to minimize the technical content of reports and to put more emphasis on broader R&D trends and general research policy matters. The technical information exchange will continue to flow through various channels throughout the rest of the year.

A statement of intention (approved by the delegates here in September) reads, in part:

"No other forum currently exists for the open discussion of varying policy objectives of electric utility research and development conducted by the various IERE countries. Accordingly, in the future, the primary objectives and focus of IERE meetings should center upon present and future trends and directions of research and development taking place in the several countries within the IERE organization, the reasons for pursuing such trends and directions, and the reasons for not pursuing alternatives to them (including such reasons as resource limitations and regulations by government).

"Among the subjects to be considered at the next meeting will be the following: (1) the influence of national perceptions of atmospheric pollutants upon the course of research and development, (2) the influence of finite fuel resources upon the course of research and development, and (3) the influence of finite water resources upon the course of research and development.

"The members agreed that the next meeting of IERE would be held in Europe under the auspices of CORECH between the 26th and 30th of September, 1977."

Reducing duplication of effort

Despite the differences in the energy problems faced by the IERE member nations, there are commonalities in the technologies for solving them. An important function of IERE is to reduce costly and time-consuming duplication of effort through international communication of these technologies.

Louis De Heem, chairman of the board of Société pour la Coordination de la Production et du Transport de l'Energie Electrique of Belgium and chairman of IERE during the past two years, has been succeeded by Dr. Lionel Boulet of Canada, director of Hydro-Quebec Institute of Research, who steps up from vice chairman.

Titles and authors of the papers presented at the eighth annual meeting of IERE are listed below. Copies of these papers are available from the EPRI Records and Reports Center, P. O. Box 10412, Palo Alto, California 94303.

□ "Research and Development in the Electric Utility Industry of Japan." Dr. Naohei Yamada, Director of CRIEPI and Principal IERE Representative for Japan.

□ "Review of Activities in the UNIPEDE Countries." Dr. M. E. A. Hermans, Deputy Director of KEMA and Chairman of CORECH.

□ "Nuclear Power—Research in the United States." Mr. Milton Levenson, Division Director of EPRI and Alternate IERE Representative for the U.S.

□ "Research and Development on Nuclear Power Generation in the Electric Utility Industry of Japan." Dr. Naohei Yamada.

□ "The Canadian Nuclear Power Program" and "Research and Development for Canadian Nuclear Power." Dr. J. A. L. Robertson, Assistant to Vice President, Chalk River Nuclear Laboratories, AECL.

□ "Research Problems in the Development of Breeder Reactors." Mr. Pierre Feintuch, General Controller, Study and Research Direction, EDF, and Member of UNIPEDE.

□ "Fossil Fuel and Advanced Systems—Research in the United States." Dr. Richard E. Balzhiser, Division Director of EPRI.

□ "Electricity from Natural Energy Sources." Presented by Mr. John Syrett, on behalf of Dr. D. J. Littler, Controller of Research of CEGB and Alternate IERE Representative for Europe.

□ "Utilization of Electric Energy and Other Forms of Energy." Dr. M. E. A. Hermans.

□ "Problems in Enlargement of Power Plant Size and Expansion of Power Systems in Japan." Dr. Naohei Yamada.

□ "Transmission and Distribution—Research in the United States." Mr. John J. Dougherty, Division Director of EPRI.

□ "Energy Systems, Environment, and Conservation—Research in the United States." Mr. René Malès, Division Director of EPRI.

□ "Effect of AC Electric Fields on Human Beings and Animals." Presented by Mr. Pierre Feintuch, on behalf of Professor T. Leardini, Central Manager, Research and Development Department of ENEL and Member of UNIPEDE.

□ "Thermal Discharges." Presented by Mr. Charles Lippens, Director General of LABORELEC and Member of UNIPEDE, on behalf of Professor T. Leardini.

□ "Recent Status of Research on Thermal Discharges in the Electric Utility Industry of Japan." Mr. Katsusuke Yoshida, Manager of the Thermal Power Department, Kyushu Electric Power Company, Inc.

Advisory Council Hosts Energy Issues Seminar

EPRI advisers and guests bring diverse points of view to the energy situation and the forces that underpin and direct it.

Basic issues relating to U.S. and international energy problems were explored at a week-long late-summer seminar, "Perspectives on Energy and Society," sponsored by EPRI and the Aspen Institute for Humanistic Studies. In an effort to develop a broader understanding of economic, cultural, and political issues often overlooked in day-to-day dealings with the energy situation, discussion topics ranged from changing population patterns to institutional obstacles to the development of coal resources.

The selection of participants, including EPRI Advisory Council members and a variety of other energy industry authorities, ensured that the discussions would be lively and agreement on any given issue would be rare. And even though the Aspen setting promoted a relaxed and contemplative atmosphere to encourage fresh perspectives, it was clear that the opinions the participants brought to the seminar were not changed materially as a result of the extensive conversations. It is more likely that the participants' ideas were sharpened by the exchanges.

There was occasional consensus, however. No one questioned the difficulties that developing nations face in combating the parallel problems of population growth and diminishing world energy resources. There were no arguments about the historical relationship between energy and economic growth, although the extension of this relationship into the future was a subject of spirited debate.

The role of the public in influencing energy policy was acknowledged by everyone, with strong differences expressed as to the implications and desirability of this relatively recent public involvement. Also, the need to utilize the nation's vast coal resources was not questioned by the participants, even though an animated discussion took place on the social, technological, and regulatory obstacles to doing so.

A new alliance?

The most volatile issue came up on the final day of the meeting. As part of the session on coal, the stage was set with a presentation by Steven Wyncoop, energy writer for the *Denver Post*. Wyncoop cautioned that plans for developing the coal resources of the West must take into consideration the growing environmental sensitivity of the people in that area and the increasing willingness of the public to question the need for growth at historical rates.

The discussion following Wyncoop's remarks was joined by Timothy Wirth, a U.S. congressman from Colorado. Wirth said he is beginning to detect an alliance of constituencies, linking environmentalists with society's disadvantaged. He said this coalition is beginning to unite the people of the inner city with those who are advocating a more measured approach to energy growth.

This observation drew a quick response from several participants. René Malès, director of EPRI's Energy Analysis and Environment Division, said his experience has shown that persons at the bottom of the economic ladder view jobs and economic growth as primary concerns rather than the lifestyle changes that would normally accompany a slower economic growth rate.

Congressman Wirth received backing from other participants, however, and only the adjournment of that final session brought the discussion to a close.

Demographic factors

The leadoff presentation of the seminar was "Energy and Demographic Change," with Everett S. Lee, professor of sociology at the University of Georgia, as discussion leader. Although Lee sees encouraging population trends in the U.S. and in other developed countries, he expressed great concern for the continuing population explosion in the rest of the world.

In developing countries, he noted, population is an obvious problem. But the composition of the population is also a matter of great concern. The labor force in the developing countries today is less than 25% of the total population, with one-half of the population being under the age of 15. This is an undesirable situation, Lee added, that will become serious when the economies of these countries require a larger work force. The western world, on the other hand, has a one-to-one ratio of people in the work force to children of school age.

Lee sees a U.S. population growth averaging 0.7% annually until the year 2010 and a zero population growth thereafter.

He sees problems for the rest of the world as the growth rate continues at a far higher pace. Considering the historical connection between energy availability and population growth, Lee feels that this continuing increase portends grave problems for many of the developing nations.

Commenting on Lee's presentation, Walter Marshall, deputy chairman of the United Kingdom Atomic Energy Authority, expressed serious doubts about the ability of the developing countries to deal with the dual problems of energy and population. The problem, he said, is "absolutely staggering," and for several of the countries any outside help that could be provided may already be too late.

Marshall added that these countries will be making massive demands on the world energy supply, and these demands will definitely affect the availability of oil in the U.S. This is as it should be, Marshall feels, since oil "should help solve man's misery," while alternative energy sources available to the U.S. should be utilized to a much greater degree.

Further discussion by the group amplified Marshall's concerns and resulted in the conclusion that China appears to be the only developing nation that has had some success in dealing with the problems of a growing population in a world of diminishing resources.

More labor, less energy?

Congressman Joseph Fisher of Virginia, a member and former chairman of the EPRI Advisory Council, suggested that one approach to the problems of the developing countries might be for them to build industry that is more labor-intensive and less energy-intensive, and these countries should begin to plan on a basis other than that energy in great quantities is absolutely essential to their advancement.

As to what general role the U.S. can play in assisting these countries, the comments were largely negative. Even if we could come up with a "perfect solution" for them, Malès asked, how would we implement it? Joseph C. Swidler, former head of the New York State Power Commission and instrumental in founding EPRI, noted also that we find ourselves in an increasingly hostile world. The prospect for peaceful and equitable solutions to worldwide problems is rather beyond our sphere of influence, Swidler said, noting that China has made its great strides totally without our assistance.

New solutions needed

The question of public attitudes and related questions of energy policy were addressed by Dr. Burkhard Strumpel, program director, Institute for Social Research, University of Michigan. Strumpel stressed that the era of "man over nature" is gone, and from now on, such an approach to the earth's resources will yield fewer benefits.

The time has come, Strumpel maintained, to question the historical growth of energy consumption and to make better use of human resources. Part of the problem, he feels, is that energy prices have been artificially low and have encouraged wasteful use of energy in industry and in agriculture.

The economy is now immune to solutions that worked 15 years ago, Strumpel maintained. Part of the solution, he feels, is to allow consumer choices to be made more freely rather than to be shaped by marketing programs. Also, he feels it may be necessary to provide assistance to the private sector in order to institute labor-intensive development programs.

Strumpel's remarks drew a quick and vocal response from many participants, with the issue of energy in agriculture as one of the prime areas for argument. Another point of contention was whether an economy oriented more to services than to goods would actually use less energy. Several of the participants felt that this premise has not been supported by evidence.

The willingness of the public—especially the American public—to conserve energy was questioned. Joel Darmstadter of Resources for the Future said that too much emphasis is being placed on the short-lived energy conservation success the U.S. experienced during the oil embargo. Darmstadter acknowledged a temporary change in consumption habits, but added that the experience was insufficient to permit a long-range understanding of public conservation attitudes.

Nuclear power defender Ralph Lapp reviewed the opinion-shaping techniques employed by nuclear opponents and offered suggestions on countering these activities.

Public involvement

On the public involvement side of the energy question, Dorothy Nelkin of the Department of City and Regional Planning, Cornell University, discussed studies she has conducted of projects in Sweden, Austria, and Holland. The three countries used various approaches to achieve public involvement in technical decisions. The development of nuclear energy was one of the central issues in all cases.

Nelkin said that it is too early to judge the effectiveness of these programs, but she expressed strong support for the premise that such technical questions are appropriate for broad public and political discussion. "In this light, the field of nuclear energy has perhaps provided a classic example of how not to develop policies for technology," she said.

She concluded that if the public decision-making process is to be workable, the public must have a way to better understand technical subjects and to accept the uncertainty connected with science and technology. There are some long-term implications as well, she said, in quoting an Austrian civil servant who asked, "What is enough democracy?" Nelkin commented that this point will require a great deal of additional study.

Martin Meyerson, president of the University of Pennsylvania, and Lawrence Eisenberg, director of the school's Energy Center, summarized the academic environment and its implications for the energy industry.

Addressing the question of why the electric utility industry does not attract the top students, Meyerson theorized that "the more regulated the industry, the less attractive it is to high-achieving students." He believes the situation will continue, and the utility industry will have difficulty attracting the talent it needs until it takes on a new image in the eyes of the students.

Eisenberg commented that the university's Energy Center is the type of institution needed to cultivate student interest in the utility industry early in their academic experience.

The energy-GNP link

Preliminary results of a study by Resources for the Future were presented by Darmstadter and Sam H. Schurr, director of the National Energy Strategies Program for RFF.

Concentrating on the historical aspects of energy and the economy, the energy analysts pointed out that the use of energy per unit of gross national product increased through World War I, declined until World War II, and has generally leveled out since then. The reason for the early increase, Schurr pointed out, is that the nation's industrial base was being put into place, and energy use was far more intensive then than now. Also, the lighter manufacturing industries and service industries that have since developed are generally less intensive energy users.

A second reason for the diminished energy use per unit of GNP was the movement toward electrification and the switch to liquid fuels, caused primarily by the internal combustion engine.

The RFF work, to be released as an EPRI final report, is expected to substantiate a link between the performance of the economy and energy consumption. Another area under study by RFF concerns the comparative energy consumption patterns in other high-GNP countries to determine the differences and similarities between those nations and the U.S.

Energy from coal

The session on coal opened with an overview report by Thomas V. Falkie, director of the U.S. Bureau of Mines. Falkie noted that coal consumption projections call for an increase from approximately 666 million tons in the U.S. today to approximately 1 billion tons by 1985. This increase will be necessary, he emphasized, if the nation is to meet its electric power production targets.

Falkie noted that while there are ample coal resources in the U.S., the availability of that coal in the long term is uncertain because of unresolved clean air issues, other pending environmental legislation, and "the continuing threat of intervention by preservationists' resisting the development of coal resources and the siting of coal-burning facilities."

Falkie's presentation was followed by others on automated coal extraction techniques; coal transportation systems; environmental, financial, and technical limitations on utility use of coal.

Seminar participants

Steven Ailes
Association of American Railroads

Tom C. Aude
Bechtel, Inc.

T. Louis Austin
Texas Utilities Company

Hon. Robert K. Bloom
Pennsylvania Public Utility Commission

Hon. Peter A. Bradford
Maine Public Utilities Commission

Dr. Charles C. Coutant
Oak Ridge National Laboratory

Joel Darmstadter
Resources for the Future

Dr. Ruth M. Davis
National Bureau of Standards

Dr. Lawrence Eisenberg
University of Pennsylvania

Dr. Merrill Eisenbud
New York University Medical Center

Dr. Thomas V. Falkie
U.S. Department of the Interior

Hon. Joseph L. Fisher
U.S. House of Representatives

Donald Hodel
Bonneville Power Administration

Russell Hulse
Arizona Public Service Company

Edward Johnson
National Bureau of Standards

Hon. Alfred E. Kahn
New York Public Service Commission

Dr. Ralph E. Lapp
Quadri-Science, Inc.

Dr. Everett S. Lee
University of Georgia

Hon. Marvin S. Lieberman
Illinois Commerce Commission

Dr. Robert L. Loftness
EPRI

René Malès
EPRI

Dr. Walter Marshall
United Kingdom Atomic Energy Authority

Parker Mathusa
New York Public Service Commission

Dr. Martin Meyerson
University of Pennsylvania

Hon. Pat Moran
Arkansas Public Service Commission

Dr. Dorothy Nelkin
Cornell University

Dr. Bruce C. Netschert
National Economic Research Associates, Inc.

Richard Rudman
EPRI

Sam H. Schurr
Resources for the Future

Dr. Chauncey Starr
EPRI

Dr. Arthur C. Stern
University of North Carolina

Dr. Burkhard Strumpel
University of Michigan

Hon. Vernon L. Sturgeon
California Public Utilities Commission

Joseph C. Swidler
Leva, Hawes, Symington, Martin & Oppenheimer

Frank M. Warren
Portland General Electric Company

Hon. Ralph H. Wickberg
Idaho Public Utilities Commission

John G. Winger
The Chase Manhattan Bank

Hon. Timothy Wirth
U.S. House of Representatives

Steven Wyncoop
Denver Post

DIALOGUE ON FUSION TECHNOLOGY

Progress in building a working dialogue between the developers and the ultimate users of a new technology was made at a major fusion energy meeting held September 21–23 in Richland, Washington.

At a meeting to discuss advances in fusion technology are (from left) the Honorable Mike McCormack, chairman of the Energy Research, Development, and Demonstration Subcommittee of the House Science and Technology Committee; Ed Kintner, director of ERDA's Magnetic Fusion Energy Division; and Bill Gough, program manager of EPRI's Fusion Program.

Sponsored jointly by EPRI, ERDA, and the American Nuclear Society, the second topical meeting on the technology of controlled thermonuclear fusion included a series of presentations aimed at building a bridge between the fusion programs of the federal government and those of the electric utility industry.

Some 350 representatives of the industry, government, and contractors involved in fusion technology development attended the meeting.

"EPRI's involvement in this meeting marked substantial progress in our efforts to incorporate the viewpoint of the electric utility industry into the early development stages of fusion technology," stated Bill Gough, EPRI's program manager for fusion power. "It was particularly significant because the dialogue included the contractors who will actually be developing the new technology. This was the first time that the utility viewpoint has been presented in such a comprehensive and far-reaching fashion."

Participants heard Chauncey Starr, president of EPRI, discuss the long lead times necessary to bring a new technology to the point where it makes a significant impact on the energy field. W. C. Wolkenhauer of Washington Public Power Supply System discussed the need for interaction between the developers and the users of fusion technology and Bill Gough described methodologies for accomplishing this interaction. Gough also outlined EPRI's Fusion Program. The unique role of fusion in the energy future was the topic of an address by the Honorable Mike McCormack, chairman of an energy subcommittee of the U.S. House of Representatives.

The federal government is spending over $200 million to demonstrate the use of fusion power for the production of electricity. The utility industry, through EPRI, is sponsoring a program to assess national and worldwide fusion efforts and to work toward development of fusion technology that will be of maximum usefulness to the industry.

Energy Modeling Forum

Greater efforts by economists and energy planners to develop, understand, and use energy models, triggered by the OPEC oil embargo a few years ago, have resulted in the recent implementation of an important EPRI project called the Energy Modeling Forum. Contracted to the Stanford Institute for Energy Studies, the project began with a workshop last summer to develop the structure of forum operations.

The rapid development of diverse energy models has not been balanced by the analysis, comparison, or application needed to ensure effective model use and improvement, according to Martin Greenberger, manager of the Systems Program in EPRI's Energy Analysis and Environment Division and manager of the forum project. "What's required," says Greenberger, "is better understanding and communication of existing model capabilities."

The Energy Modeling Forum, based on

the principle that the most effective means of broad communication is through example, will use several major energy models to explore and compare the implications of selected energy decisions and scenarios. The first study of the project, which will conclude in February, addresses the extent to which changes in the energy sector can affect economic growth. Several models will be applied to this question and the results will be compared to determine the common implications or important differences in the models. Comparisons will also help to explain the causes of the model results.

William Hogan, an adjunct professor at Stanford University, is the executive director of the project. He reports that the summer workshop participants included representatives from government agencies, energy industrial corporations, electric utility companies, universities, and research institutes so that a "user focus was provided along with different perspectives."

Hogan says that analysts are aware of an imbalance in the wealth of data contained in energy models and the lack of understanding on how to use them. "The main objective of the forum is to provide guidance on the capabilities and limitations of some of the major energy models so that users and developers can better understand the role models can play in decision making on energy issues," states Hogan.

"Although methods of analyzing energy-economy models can also be developed by commissioning disinterested specialists to study and write about some of the key energy models," comments Hogan, "the advantage of the forum approach is the wide participation it permits among persons most familiar with energy decision making."

Exhibit at IEEE

John Marks, left, and Bill Shula, second from right, of EPRI's Electrical Systems Division, review current research with visitors at the IEEE Underground Transmission and Distribution Conference held in Atlantic City last September. Conference participants also learned about EPRI's research through a series of panel discussions coordinated by Ralph Samm and Dick Steiner.

Distribution Test Requirements

"A utility should have the opportunity to find out if the components of its distribution systems will function properly before, and not after, the expense is incurred to put them on-line," states Dick Steiner, manager of EPRI's Distribution Program.

Although some individual companies do have test facilities to provide such assurance, the industry as a whole is lacking an integrated, independent service, available to all utilities. This is why EPRI is making plans to provide a testing operation where concepts, equipment, and materials for distribution systems can be examined and evaluated.

EPRI's Board of Directors approved the industrywide operation in principle at its May meeting, and a workshop was recently held in St. Louis, Missouri, July 29–30, to identify pertinent factors in developing the plans. Utility representatives, equipment manufacturers, EPRI staff, and other interested parties attended.

Workshop participants agreed on the need for industrywide testing operations managed by EPRI. They recommended testing for (1) an evaluation of product performance, (2) EPRI's internal research needs, (3) specific needs of a utility or group of utilities, and (4) needs of manufacturers and others.

Participants suggested that EPRI upgrade and use existing utility test facilities rather than construct a new laboratory. Steiner explained that under this arrangement, EPRI might contract with individual utilities for use of their facilities for a certain period of time. It would be cheaper for EPRI and would make facilities available to utilities on a wider geographic basis.

Steiner stressed that the testing program is still in a preliminary planning stage and that EPRI is seeking additional recommendations from the industry on the proposed service.

Saudi Arabian Prince Visits EPRI

His Royal Highness Prince Mohamed Al-Faisal of Saudi Arabia (left) met with EPRI President Chauncey Starr and other EPRI officials on October 21. The visit resulted from Prince Al-Faisal's interest in EPRI's fusion power program. The talks included discussions on fusion, solar, and fuel cell research at EPRI. Prince Al-Faisal is governor of the Saline Water Conversion Corporation of Saudi Arabia and a member of the nine-man governing board responsible for allocating funds from the newly created King Faisal Philanthropic Foundation. The foundation is a charitable organization with an endowment exceeding $2.5 billion for the support of medical and scientific research. Accompanying Prince Al-Faisal was Minister S. Hedayet, president of the Arab Scientific Research Council, and various technical consultants.

Materials for Coal Conversion

A conference on materials for coal conversion processes was recently sponsored by EPRI, ERDA, and the American Gas Association (AGA) in Washington, D.C.

Robert Jaffee, technical manager of the Materials Support Program in EPRI's Fossil Fuel and Advanced Systems Division, said the 160 participants reviewed EPRI and ERDA research programs in materials development and also discussed various materials problems of advanced and present fossil fuel technologies.

"Most alloys, for example, have been developed for oxidizing environments other than the low-oxygen activity and high pressures inherent in new coal conversion technologies," Jaffee said, adding that some of the alloys are not very resistant to reducing conditions or to attack by sulfur or other coal constituents.

Topics discussed at the meeting included valve erosion in coal liquefaction equipment as a result of entrained or suspended particulate matter, corrosion problems of fluidized-bed boiler tubes, hydrogen attack and temper embrittlement of pressure vessels, and the possibility of erosion from residual particulate matter in those gas turbine–combined-cycle systems that use coal-derived fuels.

At a recent conference on materials for coal conversion processes, Dr. H. E. Frankel (left), assistant director, Materials and Power Generation, ERDA Fossil Energy, confers with Dr. A. Flowers (center), executive director of AGA, and Dr. Robert Jaffee, technical manager of the Materials Support Program in EPRI's Fossil Fuel and Advanced Systems Division.

"Several kinds of chemical interactions will occur between the structural components and the high-temperature, highly reactive gases of coal gasifiers," Jaffee wrote in the July/August EPRI JOURNAL. "Moreover, the process gases will carry small particles of coal ash, uncombusted coal, and other process constituents."

In the JOURNAL article, Jaffee voiced the belief that the combination of erosion and corrosion will lead to accelerated degradation of structural materials. Thus, a significant portion of the EPRI–ERDA research is devoted to resolving this problem, as well as to the long-term behavior of materials under the mechanical loads, high temperatures, and hydrogenous atmospheres of coal-conversion pressure vessels.

The meeting was the first national conference of its kind and will be an annual event. Abstracts can be obtained from H. E. Frankel, ERDA, Washington, D.C. 20545.

Project Highlights

EPRI Negotiates 25 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP377-2	Central Receiver, Closed-Cycle Helium Solar Power Plant	16 months	407.2	Boeing Engineering and Construction Co. *J. E. Bigger*
RP629-2	Improved Fuel Evaluation Procedure and Testing Facility for Characterization of Fly Ash and for Prediction of Electrostatic Precipitator Performance	3 months	24.0	KVB Engineering *W. Piulle*
RP643-1	Parameter Monitoring for Corrosion Control in Gas Turbines	23 months	500.0	Turbo Power and Marine Systems, Inc. *R. Duncan*
RP717-2	Fluidized-Bed Combustion Retrofit Study for Conversion of Oil-fired Boilers to Coal	21 months	87.7	New York State Energy R&D Authority *S. Ehrlich*
RP725-5	Advanced Particulate Control Development and Test Facility	10 years	370.0	Public Service Company of Colorado *O. Tassicker*
RP725-7	Advanced Particulate Control Facility	1 year	363.9	Flow Research, Inc. *O. Tassicker*
RP779-4	Bench-Scale Coal Screening Tests	5 months	121.4	Hydrocarbon Research, Inc. *N. Stewart*
RP832-1	Commercial Economic Study of CDF Process	6 months	85.8	C. F. Braun & Co. *H. Lebowitz*
RP838-1	Metastable Phenomena in Hydrogen Degradation of Low-Alloy Carbon Steels	1 year	153.2	Pennsylvania State University *R. Richman*
RP844-1	Individual Load Center—Solar Heating and Cooling Commercial Project	11 months	237.0	Arthur D. Little, Inc. *J. Cummings*
RP902-1	Fundamental Studies of Mechanisms of Biofoulant Film Buildup and Destruction	16 months	79.8	Rice University *R. Jorden*
RP917-1	Network Reliability Impact of Distributed Storage Units	10 months	95.0	Systems Control, Inc. *J. Beck*
Nuclear Power Division				
RP811-1	MEKIN Transient Analysis Sensitivity Studies	2 years	211.8	Massachusetts Institute of Technology *J. Naser*
RP818-1	Development and Application of Advanced GO Methodology for Nuclear Safety Systems Assessment	14 months	94.6	Kaman Sciences Corp. *B. Chu*
RP826-1	Optimization of Reliability Data Systems	11 months	143.9	Holmes & Narver *R. Long*
RP826-2	Optimization of Reliability Data Systems	1 year	49.9	S. M. Stoller *R. Long*
RP827-1	Analysis of Dosimetry Measurements in Reactor Cavity of LWRs	2 years	110.6	Science Applications, Inc. *F. Rahn*
RP895-2	Fuel Reliability Correlation and Improvement Using Power Shape Tracking of Core Maneuvers	1 month	10.0	Systems Control, Inc. *B. Zolotar*
Electrical Systems Division				
RP792-3	Wind-induced Conductor Motion	1 year	94.2	Boeing Engineering and Construction Co. *A. Johnson*
Energy Analysis and Environment Division				
RP804-1	Computer System for Assessment of Coal Reserves	10 months	50.0	Union Carbide *T. Browne*
RP856-1	Assessment of Biogenic Sulfur Emissions	9 months	298.3	Washington State University *A. Stankunas*
RP865-1	Availability of Uranium from 'Overlooked' Domestic Deposits	8 months	59.1	Nuclear Assurance Corp. *J. Platt*
RP875-1	Energy Model Comparative Analysis	6 months	100.0	Stanford University *M. Greenberger*
RP876-1	Methodology for Assessing Ecosystem Effects Related to Intake of Cooling Waters	3 years	501.7	Lawler, Matusky & Skelly Engineers *R. Goldstein*
RP877-2	Effects of Thermal Power on Aquatic Environmental Program	18 months	75.0	Union Carbide *R. Goldstein*

Electric Utility Rate Design Study

The idea of basing the price of electricity on the time of its use has considerable support in the electric utility industry, according to a progress report released in October by the Project Committee of the Electric Utility Rate Design Study.

Peak load pricing, as this is called, is acceptable to many company ratemakers and to state regulators because it permits electric rates to closely follow a utility's costs. Such pricing would encourage customers to use electricity more efficiently. In addition, the study notes that customers could benefit if they shifted some of their electric usage to off-peak periods.

However, peak load pricing or load management might be cost-effective for some utilities but not for all, the report cautions. The report also emphasizes that many objectives must be considered in designing electric rates.

The nationwide research study is being conducted at the request of the National Association of Regulatory Utility Commissioners (NARUC) by EPRI, the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association. The Project Committee is a group of industry and regulatory officials that guide the study and ensure that the research is responsive to NARUC's needs.

The purpose of the $1 million study, which is still under way, is to evaluate the feasibility, cost, and technology of time-of-day pricing in particular and various load management techniques in general. *Load management* is a term that refers to those utility policies that attempt to balance customers' needs and the utility's capacity to provide electric service.

In commenting on the report *Rate Design and Load Management*, Robert Uhler, the study's executive director, said that electric utilities must have sufficient generating capacity to meet the growing needs of their customers. But customers' demands are not uniform, either on a daily or on a seasonal basis. Similarly, a utility's operating costs vary over the day. A closer matching of the users' needs and the utility's capacity could benefit both electric utilities and their customers.

One possible way of accomplishing this is by charging more for power used during hours of peak customer demand and less at other times. In this way, electric rates would closely track a utility's costs. With peak load pricing, consumers would benefit by using their appliances at times during the day when electricity-generating costs are lowest.

Uhler comments that such changes in the timing of consumption would reduce peak demand by shifting some loads to off-peak periods and would allow the utility to run its plants and serve its customers more effectively.

"Peak load pricing is just one tool, an indirect one, of load management," Uhler says. "A radio-operated switch on a customer's water heater, or other controls, are direct methods that could also be used to manage loads."

The crux of the study is to determine whether the costs of implementing peak load pricing or installing direct load controls on a specific utility system are more than offset by the savings achieved as a result of shifting loads and reducing peak load growth. Peak load pricing, for example, would involve extra metering costs, and direct controls would also require additional investments.

Uhler cautions that "no final conclusions can be reached until all the research has been completed." He emphasizes that although it might make sense for a particular utility to use either direct controls or peak load pricing, to impose such policies on all electric utilities is not warranted by the research accomplished so far.

Each utility must make a careful cost-effectiveness study of the different load management options available to it before moving ahead, Uhler says. "Many such analyses, experiments, and field tests are under way and are summarized in the progress report to NARUC. Two major tasks of the study are an appraisal of different costing techniques and the evaluation of several rate design concepts for peak load pricing."

The progress report to NARUC outlines the major issues of electric utility rate design and describes three alternatives: traditional pricing; time-of-day rates, using average costs; and peak load pricing based on marginal costs. Moreover, the report discusses rate design in relation to various regulatory objectives, such as the necessity of realizing adequate revenues, the importance of apportioning costs fairly among customers, and the desirability of achieving economic efficiency. More generally, providing reliable electric service at the lowest possible cost to consumers is the mandate of the industry and a prime objective of regulators. The rate design report comments on these concerns.

"While there is substantial support for extending the concept of peak load pricing," the report states, "it should be stressed that direct load controls may also be a useful method for dampening peak load growth, either as a complement or as an alternative to time-differentiated rates." The report notes that because total metering costs and peak response of customers to price signals are hard to estimate, load shifting by controls might offer a cost-effective, direct method for managing peak demands for some utilities and their customers. Seasonal rates that use existing meters might be a pragmatic approach in some cases.

The progress of research in 10 topic areas is detailed in the report. A market research firm, for example, has conducted a study of customers' attitudes and acceptance of various rate design options and is now surveying customers who face time-differentiated rates or who are using electric service under various load management practices. In addition, the results of several engineering studies are reported. Additional research is planned for the coming year.

A final report will be submitted to NARUC by the Electric Utility Rate Design Study in March 1977.

Biogenic Sulfur Pollution

"Determining how much sulfur in the air is caused by industry and how much exists in nature could strongly influence the way in which scientists go about reducing air pollution," says EPRI's Alex Stankunas in announcing a new study under way in this area.

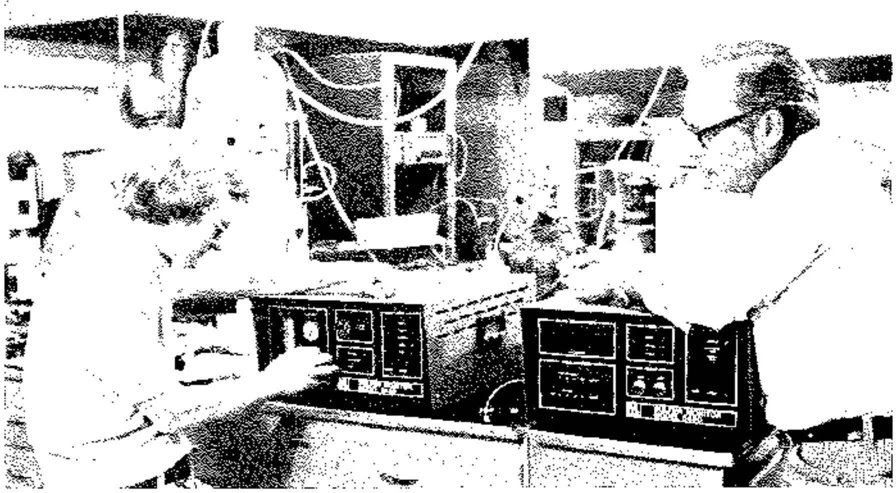
The EPRI study will help scientists learn how much, what kind, when, and where nature is contributing to the sulfur pollution problem. "The research will provide a better understanding of the whole emission-transport-removal cycle for sulfur compounds," states Stankunas, a project manager in the Environmental Assessment Department.

EPRI researchers believe that by understanding the relation between man-made and natural sulfur emissions, time and money won't be wasted in trying to change those processes that are beyond human control.

The study, being conducted by Professor Donald Adams and Dr. Sherry Farwell of Washington State University, will involve scientists working from mobile laboratories in the eastern United States to measure the emissions of sulfur compounds from different types of soil, plants, and bodies of water.

Only recently has equipment sensitive enough to detect natural sulfur emissions been available. Natural sulfur emissions, unlike sulfur emissions from a smokestack, for example, are generally very dilute. What makes them significant is that an emitting source covering hundreds of square miles may be involved.

Dr. Sherry Farwell (left) and Professor Donald Adams of Washington State University check the type of analytic equipment that will be modified for an EPRI research study on biogenic sulfur emissions.



The Washington State scientists will be developing and refining new systems for sampling and analysis that are much better than anything previously used.

During the spring, summer, and fall, field samples from eight different ecological systems will be collected. Results will be used to estimate the overall importance of each type of system to the air quality of the region under study.

"Until now, most estimates of natural sulfur emissions were derived by adding up all the sulfur we couldn't explain and calling it biologic in origin," comments Stankunas, adding that this study represents a "small but significant step forward" in trying to understand our environment.

Fuel Processing for Fuel Cells

An energy project to broaden the range of petroleum fuels that can be used by fuel cell power plants has recently begun at EPRI. The nine-month, $94,000 effort will be conducted by Catalytica Associates.

Fuel cells work by converting chemical energy directly into electricity through an electrochemical process. This direct conversion process makes fuel cells more energy-efficient than a heat engine and also offers clean and quiet electricity generation.

A fuel cell power plant consists of three basic segments: a fuel processor, the fuel cell stack itself, and a power conditioner. The fuel cell stack uses a hydrogen-rich fuel, which it gets from the fuel processor's conversion of fossil fuels to hydrogen. The electricity that results is direct current, which is converted into alternating current for transmission purposes by the power conditioner.

The first generation of fuel cell power plants, expected to be commercially available by the early 1980s, will be limited to high-quality, low-sulfur petroleum fuels, such as naphtha. EPRI energy specialists assert that the project will help ensure sufficient fuel supplies for second-generation fuel cell power plants by permitting them to use other types of fuel, such as high-sulfur No. 2 distillate oil.

The project calls for the analysis of current and advanced processing techniques for converting No. 2 distillate oil to a hydrogen-rich gas. From this analysis, researchers will evaluate the compatibility of the processes with fuel cell power plant integration. Recommendations will then be made to develop those processes that seem promising.

5% of Nation's Electricity From Storage

Up to 5% of the total electric energy needs and up to 17% of peak time electricity could eventually be supplied from energy storage systems, according to a recent study supported by EPRI and ERDA. The report marks the first major U.S. study to assess the value of new energy storage systems in meeting the nation's electric energy demand. It was done primarily to help EPRI and the federal government plan development programs for energy storage technology.

"Energy storage can play an important role in providing generating capacity for peaking and intermediate electric loads if sufficient baseload capacity is available for charging energy storage systems with off-peak energy," states the report, *An Assessment of Energy Storage Systems Suitable for Use by Electric Utilities.*

Prepared by Public Service Electric and Gas Company of New Jersey, the EPRI report discusses the potential for energy storage by electric utilities, as well as the energy storage technologies currently being considered for utility applications. Although hydro-pumped storage is the only energy storage technology widely used by electric utilities today, other storage methods, such as compressed air, thermal storage in hot fluids, and batteries, may help level electric utility loads in the future.

The idea behind load leveling is to store the relatively cheap energy generated by baseload power plants during night and weekend periods and use it to meet daily periods of peak power demand. Since baseload power plants use coal or nuclear fuel, utilities could use energy storage to reduce their dependence on expensive and scarce fuels—the oil and natural gas presently used by some steam plants and all gas turbines to meet intermediate and peak power demands.

In assessing the individual storage technologies, the report notes that over the next 10 years, hydro-pumped storage with an underground reservoir, compressed-air storage, and thermal (heat) storage are likely to become economic methods for providing peaking and intermediate power.

Advanced batteries and hydrogen storage systems could reach the commercial market after 1985, according to the report. Advanced battery systems, in particular, are likely to be sufficiently compact, economically attractive, and environmentally acceptable for dispersed siting throughout utility systems. Dispersed siting permits power generation closer to where it's actually needed, thus reducing transmission costs and increasing the efficiency of electricity delivery.

Other technologies, such as conventional lead-acid batteries, flywheel storage systems, and energy storage in superconducting magnets were cited in the report as being "generally unattractive," except in special situations or if major technical and economic advances are achieved.

The report also emphasizes that energy storage in itself is not an energy source. "It will be necessary to continue building and operating baseload coal and nuclear generating stations if energy storage is to fulfill its promise."

New Development in Solar Power Plants

A large receiver filled with helium sits atop an 80-story tower surrounded by half a square mile of reflectors. By tracking the sun all day, the reflectors radiate energy equivalent to 1000–2000 suns to the receiver. Heated to 1500°F, the helium in the receiver is run through a turbine to produce electricity and then through a dry-cooling tower to be reused.

This central receiver concept for tomorrow's solar energy power plants is one of two technologies being given strong support by the nation's electric utility industry. In the other central receiver concept, air is the working fluid instead of helium. The air, heated to 2000°F, is exhausted into the atmosphere after having been used to make electricity, and a cooling tower is not required.

These concepts are now being designed into 1-MW bench-scale model receivers for construction and testing. Boeing Engineering and Construction and Black & Veatch Consulting Engineers, two companies that have worked extensively on gas-cooled, central receivers under EPRI sponsorship, will continue their research with new contract awards totaling $1.5 million. Boeing has been working on closed-cycle helium receivers; Black & Veatch has been investigating open-cycle, air-cooled receivers.

John E. Bigger, a project manager in the EPRI Solar Energy Program, states that materials testing will be an important consideration in the design, fabrication, and testing of these models. "Understanding how materials perform at very high temperatures is crucial to the development of gas-cooled, solar energy power plants," says Bigger. He adds that Boeing has tested superalloy metals, such as Inconel 617 and Haynes 188, while Black & Veatch is evaluating ceramics for its receiver design.

"After the 1-MW tests have been completed, one of the designs will be selected for demonstration in a 10-MW central receiver pilot plant scheduled for operation in mid-1981," Bigger commented.

The EPRI program for developing second-generation solar-thermal power plants is designed to be complementary to the federal government's efforts in solar-thermal work. Through ERDA, the government is developing first-generation solar-thermal power plants and is anticipating the operation of a 10-MW central receiver pilot plant by late 1980.

"The first-generation plants differ from second-generation plants in that steam is used for the heat transfer fluid instead of gas," says Bigger. He explains that EPRI's program offers an alternative to large cooling-water requirements, which is especially significant since most solar-thermal plants will be sited in the arid regions of the southwestern U.S.

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

Electrical Systems

TD-136 REDUCTION OF AC LOSSES IN HIGH-TEMPERATURE SUPERCONDUCTORS
Final Report (RP7845)

The objective of the program was to study the feasibility of using NB_3Ge as an ac superconducting power transmission cable material. Specifically, this program was to measure ac losses in available samples of Nb_3Ge and find under what conditions the losses can be reduced to 10 $\mu W/cm^2$ at ~15°K.

Tasks of the program were (a) to make ac loss measurements on Nb_3Ge prepared at the Los Alamos Scientific Laboratory and (b) to give metallurgical treatment to sample surfaces to reduce losses. *University of Southern California*

7813-1 DEVELOPMENT AND FIELD TRIAL OF VI-LN2 CRYOCABLES—STAGE 1: 138-kV SINGLE-PHASE TERMINATION
Final Report

This report describes the development and field trial of the first cryocable termination intended for 138-kV underground power transmission lines cooled by liquid nitrogen and thermally and electrically insulated by a common vacuum space and solid dielectric conductor supports.

The field trial has proved that liquid nitrogen can be transferred from a grounded metallic LN2 transfer line to the high-voltage conductor of a 138-kV transmission system. It further demonstrated that an air-insulated high-current conductor can be passed from ambient temperature to −194°C through the termination within a distance of only 3 ft.

It is now confidently expected that the vacuum-insulated LN2 cryocable will not require superinsulation and that the electrical insulation also satisfied all thermal insulation requirements. Consequently the vacuum-insulated LN2 cryocable will be structurally similar to three-phase SF_6 insulated cables, but the aim is to make it very much more compact. *Underground Power Corp.*

Energy Analysis and Environment

EA-43-SR PLUTONIUM: FACTS AND INFERENCES
Special Report

EA-43-SY PLUTONIUM: FACTS AND INFERENCES
Summary Report

This report reviews the knowledge that we have about plutonium and the implications for society of the creation of this element in the nuclear power industry. It should help promote an understanding of the issues discussed: properties of plutonium, release of plutonium into the environment from the nuclear power industry, plutonium in the biosphere, plutonium and human beings, and diversion of plutonium for malevolent purposes.

In the report itself there was an attempt to avoid stating conclusions. However, the contributing authors did express a general view based on their collective experiences stated as follows: ". . . whereas plutonium should in no way be discounted as a hazard to human health, it does not critically limit nuclear power safety and is not uniquely hazardous nor more difficult to control than many other substances that are safely and commonly handled in our industrial society. The broader policy decision about nuclear power should, we believe, be based on the best judgment possible as to whether or not it provides a net benefit to society."

A 16-page summary of the report is also available, EPRI EA-43-SY. *C. L. Comar, EPRI*

EA-178 ECOLOGICAL INFLUENCE OF ELECTRIC FIELDS
Interim Report 2 (RP129)

Preliminary results are presented of studies on effects of electric fields on plants, voles, chicks, and chicken embryos. Electric fields no greater than 17.2 kV/m are anticipated 2 m above ground level underneath 1500 kV transmission lines. Minor plant leaf tip damage was observed for certain pointed leaves at field intensities at or greater than 25 kV/m, but none at 20 kV/m or less. Meadow voles were exposed to 50 kV/m fields for periods up to four weeks but showed no statistically significant effects of this exposure. Chicks exposed to 40 kV/m fields exhibited a short-term increase in early growth, but there were no observed differences between exposed and unexposed chicks 20 days after hatching. No effects were observed of short-term exposure to fields of up to 67 kV/m on egg hatchability or embryo behavior. *Westinghouse Electric Corp.*

EA-237 COAL TRANSPORTATION CAPABILITY OF THE EXISTING RAIL AND BARGE NETWORK, 1985 AND BEYOND
Final Report (RP437-1)

This study investigated the ability of the nation's rail and barge network to move 600 million tons of domestic coal (estimated requirement for 1985) and more numerous shipments of other commodities.

Two coal production-consumption scenarios were designed and used to test the capability of the transportation network. Analysis was made, using a detailed representation of the rail and barge network. This network data base contains the characteristics of approximately 14,000 rail origin-destination links. The study focused on 162 links that are located on 16 strategic boundaries defined by such geographic features as mountain ranges and rivers where the capacity of the links cannot be increased easily.

For the highest production case, 11 of the 16 strategic barriers had one or more overloaded links. Certain key locations on inland waterways are already constrained by congestion. (Overload on some links does not mean that the network cannot move the postulated volumes of coal but that such movement would require use of less direct routes, involving more time, equipment, and higher costs.) The analysis assumes that roadbeds are maintained, that equipment is acquired as needed, and that additional track is constructed. The reality of these assumptions, the cost and problems of moving coal around overloaded links, and the economics of rail and barge movement of coal relative to alternative means of moving fuel and energy are matters for future study. *Manalytics, Inc.*

EA-242 DEVELOPMENT OF METHODS FOR FORECASTING THE NATIONAL INDUSTRIAL DEMAND FOR ENERGY
Final Report (RP433-1)
The research results detailed in this final report represent the first step in the Demand and Conservation Program's effort to produce models that will be used to generate conditional forecasts of energy usage behavior in the materials processing sector (manufacturing, mining, and agriculture). Morris R. Norman and R. Robert Russell of Econometrica International focused primarily on developing a methodological framework for models constructed to forecast energy demand by fuel type for manufacturing industries. In addition to the theoretical work, the Norman-Russell project also produced a data base and preliminary empirical results for the two-digit (SIC) industries. *Econometrica International*

Fossil Fuel and Advanced Systems

ER-215 FUSION REACTOR PHYSICS STUDIES IN THE DC OCTOPOLE
Final Report, Task A (RP115-2)
One of the key problems for the conceptual design of a tokamak fusion power reactor is the kind of plasma instabilities that can be expected under reactorlike conditions and the effect these instabilities will have on plasma confinement. The trapped particle instabilities are theoretically expected to occur in reactorlike regimes in which the particle mean-free path length between interparticle collisions greatly exceeds the device major radius, and to be responsible for the majority of plasma transport out of the device. This transport will determine the minimum size of the fusion reactor capable of obtaining the plasma confinement time required for reactor ignition. Since the reactor cost rises very rapidly with increasing size, the trapped particle instabilities have a very strong effect on the economic feasibility of the tokamak fusion power reactor.

An experimental study of the effect of plasma particle trapping in a nonuniform magnetic field was carried out for EPRI by General Atomic Co. The study was done in the dc octopole, a machine that is capable of operating in the parametric regime in which the trapped ion modes are theoretically predicted to occur.

This report covers progress made during the last year in plasma confinement, fluctuation analysis, and plasma heating by high-frequency electric fields in the various trapped particle regimes. It also covers equipment modifications required to enter the desired parameter ranges. *General Atomic Co.*

ER-216 APPLICATIONS OF LOW ATOMIC NUMBER CERAMIC MATERIALS TO FUSION REACTOR FIRST WALLS
Final Report, Task B (RP115-2)
The first wall of a fusion reactor must withstand the impact of energetic charged particles and photons escaping from the plasma as well as of intense neutron flux. Furthermore, penetration of the plasma of material eroded from the first wall will have a detrimental effect on the plasma energy balance. Therefore, the design and materials selection for the first wall of a fusion reactor represents one of the critical problem areas for achievement of fusion power.

This report summarizes work in two areas. The first is preliminary experimental investigation of the effects of MeV He^+ bombardment on carbon and silicon carbide. The results, especially for silicon carbide, showed that these high-energy ions can result in large effective sputtering coefficients and may contribute significantly to projected first-wall erosion rates. The second is the evaluation of the potential capabilities of several conceptual designs using low atomic number materials. Permissible wall loadings range from 0.5 to 5 MW_n/m^2 or more, depending on the design concept, material choice, and desired lifetime.

Conceptual designs are presented for radiating and convectively cooled first-wall panels using near-isotropic graphite and hot-pressed and self-bonded silicon carbide. Other designs are shown for direct-contact liners, for a rotating limiter with in situ replenishment of the erosion surface, and for a self-adjusting support mechanism to ensure uniform charged particle heating of the individual wall panels. *General Atomic Co.*

ER-217 SOLAR WATER HEATING AND DATA MONITORING SYSTEMS AT SOUTH COUNTY HOSPITAL, WAKEFIELD, RHODE ISLAND
Topical Report (RP554-1)
In this report on the installation and instrumentation of a solar hot water heating system at South County Hospital, Wakefield, Rhode Island, a complete description of the solar system, the instrumentation package, system plumbing, controls, and mounting is provided. Included in the system description are its application and performance, discussion of system plumbing, control logic, and collector mounting. The instrumentation package is introduced via methodology, general description, and functional block diagrams. Each component is discussed further in detail, together with anticipated component and system accuracies, cost, and delivery data.

As anticipated, certain instrumentation system design and installation problems arose both during in-house testing and following startup at South County Hospital. These are summarized in the Appendix. *Daystar Corp.*

EM-226 DEVELOPMENT PROGRAM
FOR SOLID ELECTROLYTE BATTERIES
Final Report (RP127)

This report presents results obtained in TRW's sodium-sulfur battery program during the period from 1 July 1975 to its conclusion on 30 April 1976. The sodium-sulfur battery uses molten sodium and sulfur as the active electrode materials, employs a solid electrolyte (beta alumina), and is operated at 300–350 °C. The system is particularly promising for utility application because of the intrinsically low materials costs.

The TRW cell design differed from those employed in other domestic sodium-sulfur battery programs in that the solid electrolyte was planar rather than tubular. This approach was advantageous from the standpoint of cell component cost and battery system design. These advantages were unfortunately obtained at the expense of a more complicated cell seal.

The study demonstrated that the major challenges of developing the sodium-sulfur battery into a commercially viable energy-storage system are (1) development of corrosion resistant sulfur-electrode containers, (2) design and development of a less highly stressed seal, (3) fabrication of long-life electrolytes, and (4) design of cells capable of full utilization of the active positive-electrode material (sulfur). *TRW Inc.*

EM-227 INVESTIGATION OF MULTI-RING
FIBER-COMPOSITE FLYWHEELS FOR ENERGY STORAGE
Final Report (RP269-2)

This final report under EPRI Contract 269-2 follows that of the first year's work under EPRI Contract 269-1 for the development of high-density inertial-energy storage. The two reports cover the construction of the test facility and the testing of multi-ring rotors.

Under RP269-2 the development of high-density inertial-energy storage was continued. The program for developing methods of supporting and testing flywheels of two concentric fiberglass-epoxy rings was extended to designing five-ring systems. Limiting strength tests were performed.

The objective of RP269-2 was to compare performance with predictions based on the conventionally measured properties of the materials used and to develop specifications for materials and fabrication procedures to produce concentric ring flywheels of predictable performance.

During the year, the program was continued as planned, except that the high-speed motor was not installed and the cyclic tests on materials were not performed. Sets of filament-wound fiberglass-epoxy rings for construction of flywheels of a maximum of five concentric rings were fabricated and delivered before the end of the year.

Development of both mechanical and elastomeric concentric ring support systems was continued. Designs for the support of the full complement of five rings were completed, and fabrication of inter-ring spacers was started. The design was completed for a large hub to support a single 30-in-diam ring (which would permit limiting-stress tests to be made independently of the concentric ring development program) and fabrication was partially completed. *William M. Brobeck & Associates*

AF-234 THE APPLICATION OF LUMMUS ANTISOLVENT
DE–ASHING TECHNOLOGY TO A SOLVENT–REFINED
COAL SOLUTION
Final Report (RP524)

In July 1975, The Lummus Company was authorized by EPRI to investigate the application of the Lummus antisolvent de-ashing technology to the solvent-refined coal (SRC) liquefaction process. First, in its antisolvent de-ashing pilot unit, Lummus was to process a feedstock provided by EPRI's Wilsonville SRC pilot plant. Second, an economic comparison was to be made of the Lummus de-ashing process and rotary pressure precoat filtration. This comparison was to be made on a scale equivalent to a commercial size SRC liquefaction complex.

An ash-containing coal liquefaction product solution (derived from Illinois No. 6 coal) prepared by the Wilsonville SRC plant was de-ashed in the Lummus antisolvent de-ashing plant. An ash removal efficiency of 99.6% was achieved, which is equivalent to a recovered heavy (+699.9K or +800°F) SRC product residual ash content of less than 0.1 wt%. About 77.2% of the total quinoline-soluble heavy SRC product and 74.8% of the benzene-insoluble heavy SRC product present in feedstock were recovered with the substantially ash-free overflow stream in the de-ashing run.

For the base case considered, the total manufacturing cost of antisolvent de-ashing was less by 20–26¢/10^6 Btu or \$1.37–\$1.78/bbl SRC product than that of rotary pressure precoat filtration. The capital requirements of the two processes also differed significantly. A total installed cost (including a delayed coker) of \$57 $\times$ 10^6 and a total capital requirement of \$73.5 $\times$ 10^6 were estimated for antisolvent de-ashing facilities; a total installed cost of \$99 $\times$ 10^6 and a total capital requirement of \$131 $\times$ 10^6 were estimated for filtration de-ashing.

It was concluded that the Lummus antisolvent de-ashing technology is the preferred technically and economically viable alternative to rotary pressure precoat filtration when applied to the ash-removal step of the SRC process. *The Lummus Company*

FP-257 EFFECTIVENESS OF GAS
RECIRCULATION AND STAGED COMBUSTION IN
REDUCING NO_x ON A 560-MW COAL-FIRED BOILER
Final Report (RP530-1)

This report summarizes the emissions and operational performance of a large (560-MW) pulverized-coal-fired utility boiler operating with windbox gas recirculation and two-stage combustion for emissions control. The study evaluated the relative effectiveness of these techniques and their impact on boiler and precipitator performance.

The more stringent limits on NO_x emissions imposed by local air pollution regulatory agencies and the EPA New Source Performance Standards (0.7 lb/10^6 Btu) have emphasized the need for effective NO_x reduction techniques that also maintain good boiler operations. The study provides extensive full-scale test data for comparing these techniques. *KVB, Inc.*

ER-258 SOLAR DATA VERIFICATION PROJECT
Final Report (RP552)
Solar data are essential to the electric utility industry for the prediction of the impact (on electric power demand) of large-scale implementation of solar energy systems. Identification of adverse impacts will assist in the development of preferred systems and in support of rate requests designed to minimize adverse effects.

The report presents the current status of solar energy resource data and describes a systematic program to acquire high-quality data in a form relevant to practical applications of solar energy. The report is based upon a six-month study that had as its goals the definition of current solar energy resource data and assessment of their adequacy; the description of instrument systems for use by the electric utility industry to independently collect relevant data; and the determination of the degree of standardization and centralization desirable in such an effort, particularly in data analysis. *Science Applications, Inc.*

EM-264 AN ASSESSMENT OF ENERGY STORAGE SYSTEMS SUITABLE FOR USE BY ELECTRIC UTILITIES
Final Report, Volume I and Volume II (RP225)
This report addresses the entire range of energy storage technologies and identifies the potential effect of energy storage on U.S. electric utility systems.

It was concluded that energy storage could provide generating capacity for peaking and intermediate electric loads if sufficient economic baseload capacity is available for charging energy storage systems with off-peak energy. If energy storage efficiencies of 75% can be achieved, approximately 5% of U.S. electric energy requirements could be supplied by energy storage. If sufficient off-peak coal and nuclear energy is available, energy storage could provide for up to 17% of peak load demand. In addition the various energy storage technology options are described and compared both in regard to present status and future potential.

Volume I provides a summary of the report; Volume II contains the full details of the study. *Public Service Electric and Gas Co.*

Nuclear Power

NP-152 STUDY OF RADIATION DOSAGE TO STRUCTURAL COMPONENTS IN NUCLEAR REACTORS
This report, reviewed in last month's JOURNAL, presents detailed calculations of the neutron and gamma ray fluence in and around the reactor vessels of both pressurized water and boiling water reactors. These analyses were performed with the two-dimensional discrete ordinates code, DOT.

Subsequent to the publication of the report it was found that the calculations did not adequately define the geometry and that the published predictions are low, particularly in the area of the pressure vessel. Science Applications, Inc., is evaluating the results and a revised report will be published during the spring of 1977. Questions concerning the progress in revising the results may be directed to Frank Rahn at EPRI. In order to avoid confusion, it is suggested that existing copies of NP-152 be destroyed.

NP-197 A REVIEW OF THE RATIONAL APPROACH TO TWO-PHASE FLOW MODELING
Topical Report
The solution of many nuclear engineering problems, such as those associated with a postulated loss-of-coolant accident, requires the ability to calculate fluid flows involving several material phases. These flows are known to occur over a wide range of regimes, and correlations for the mass and heat fluxes for the most idealized cases have been studied experimentally. In practical situations, however, these idealized flow patterns may occur only in part, in combination, or may not occur at all. Furthermore, since such flows vary rapidly in time, they may have properties unlike their well-studied, steady counterparts. Consequently, the successful application of the advanced computer codes presently under development at EPRI depends critically on the ability to model this complex behavior.

One of the most promising methods for obtaining reliable models is based on a mathematically rigorous derivation of the equations governing the dynamics of each phase and their interaction with each other. This is the so-called rational approach to modeling.

This report reviews and extends the general concepts of the rational approach. The equations for two-phase flow are derived in a convenient form, and intuitive interpretations of the abstract mathematical operations are given to help guide the choice of models. *Jaycor, Inc.*

NP-225 A STUDY OF ZIRCALOY-4–STEAM OXIDATION REACTION KINETICS
Final Report (RP249-1)
A better understanding of oxidation kinetics of Zircaloy-4 in flowing steam is needed for modeling cladding behavior during a postulated loss-of-coolant accident (LOCA) in light-water-cooled nuclear power reactors. During such an incident, oxidation would occur over a wide temperature range and under heating and cooling rates that are substantially different at various times into the transient. Current licensing criteria for emergency core cooling systems for LWRs require an isothermal oxidation kinetics model in all computer codes used to characterize cladding behavior during postulated transients. Isothermal oxidation kinetics are required to calculate energy release rate, extent of oxidation, and hydrogen generation during the transient. If these codes are to yield a realistic prediction of cladding behavior, it is essential that any limitations on the accuracy and use of isothermal oxidation kinetics be understood.

These criteria could lead to deratings or to reductions in operating flexibility in some nuclear power plants. The objective of 249 is to address this problem by providing realistic isothermal and transient Zircaloy oxidation models.

The project report presents isothermal and transient oxidation data for Zircaloy-4 in unlimited steam obtained from experiments using a Gleeble device, which accurately controls temperature and time during the oxidation process. In addition, comparison is made with two modeling codes under development to predict behavior of Zircaloy-4 under both isothermal and transient oxidizing conditions in steam. The first code, designated TRANS 1, is based on using isothermal oxidation reaction kinetics in modeling oxidation under transient conditions. The second code, ZORO 1, considers the fundamental variables of oxygen diffusion and interface oxygen concentrations associated with the developing oxygen concentration profile in the Zircaloy to predict cladding behavior in steam under transient oxidizing conditions.

Data from short sections of Zircaloy tubing were obtained from measurements of oxide thickness on metallographic cross sections following exposure to steam under conditions where temperature control was accurately maintained by a high speed, time-temperature controller. The isothermal oxidation data confirm that the Baker-Just equation is quite conservative at the high temperatures appropriate to postulated LOCAs. The models of Zircaloy oxidation under development provide reasonable estimates of the measured extent of oxidation under simple transient conditions. *Worcester Polytechnic Institute*

NP-238 LIDAR OBSERVATIONS OF PLUME DIFFUSION AT RANCHO SECO GENERATING STATION
Final Report (SOA 75-316)

This study has demonstrated that the lidar (light detection and ranging) is a valuable remote sensing observational tool for field studies of the spatial and temporal variations of effluent plumes released to the atmosphere. The major objective of the study was to determine the feasibility of using the Mark IX lidar and its associated digital data system to obtain quantitative measurements of plume diffusion using a smoke tracer. The smoke tracer was released from the reactor containment building at the Rancho Seco generating station.

The plume cross sections were sampled at various distances downwind of the release point. The results of 10 lidar observational runs are presented on a run-by-run basis in this report. Provided with each observation are a brief qualitative discussion of noteworthy features of the data, identifying information for the lidar scans, and photographic results of the lidar elevation scans in the form of digital computer-generated vertical cross sections of relative plume density. Lidar-observed vertical diffusion parameters (σ_z) are compared to Pasquill-Gifford values. The lidar-observed values are consistently higher than the Pasquill-Gifford values by an amount equivalent to the wake correction factor. *Stanford Research Institute*

NP-239 APPLICATION OF GLOBAL-LOCAL FINITE ELEMENT METHOD TO FRACTURE MECHANICS
Technical Report 1 (RP299-1)

This study describes an efficient solution algorithm for linear fracture mechanics with the global-local finite element method. The computer program, GLASS I, is not in its optimum form since the initial effort was to show applicability. A more user-oriented version, GLASS II, is being developed and will include an efficient input data stream and automatic satisfaction of constraint requirements at the global-local interface.

The encouraging results from the two-dimensional crack analysis have led to extending its application to linear three-dimensional fracture analysis and seismic wave propagation in the soil-structure interaction area. *University of California at Los Angeles*

NP-254 STUDY OF REMOTE MULTIPLEXING FOR POWER PLANT APPLICATIONS
Final Report, Volume I (RP513)/Final Report, Volume II (RP513-1)

Remote multiplexing systems (RMS) are of increasing interest to the utilities as an alternative to conventional hardwiring used for the collection and transmission of data and control signals to and from the thousands of devices in a power plant. Volume I presents a state-of-the-art survey that includes: 1) an overview of RMS design, 2) a review of typical commercial applications, 3) a summary of utility industry acceptance, 4) partial descriptions of commercially available RMS, and 5) a comprehensive bibliography of relevant articles and standards. This information will acquaint the reader with the basic concepts of remote multiplexing and its inherent advantages and disadvantages. Detailed technical analyses are to be presented in Volume III.

Volume II presents a methodology for tabulating signal and wiring requirements for a power plant and contains actual data for five generic types of plants (BWR-GE, PWR-B&W, CE, W, FOSSIL). The information has been tabulated in sufficient detail to permit establishment of realistic functional requirements for a number of categories of remote multiplexing systems (including plant-wide instrumentation and control, distributed intelligence, safety systems, RMS). Although these data will not be identical to those of any specific plant, the level of detail should provide the interested reader with an excellent starting point or base reference. Because of the specialized nature of this second volume, it will be distributed on a limited basis; however, copies may be obtained on request from EPRI. Volume I—*TRW Systems and Energy Group*/Volume II—*United Engineers and Constructors, Inc.*

NP-260 STEALTH, A LAGRANGE EXPLICIT FINITE-DIFFERENCE CODE FOR SOLIDS, STRUCTURAL, AND THERMOHYDRAULIC ANALYSIS
4 Volumes (RP307 Computer Code Manual-4)

This code offers an alternative in the public domain of a general, modular, user-oriented, explicit finite-difference program to address transient, nonlinear events. All computing techniques (e.g., finite-element or finite-difference, Eulerian or Lagrangian formulation, implicit or explicit integration) normally show certain advantages in particular situations with overlapping areas of common efficiency. EPRI's STEALTH code has been formulated in a Lagrange description for a general continuum that may include solids, fluids, and mixtures.

It is anticipated that STEALTH will be applicable in design situations such as water-hammer, soil-structure interaction, missile impact, mixed phase fluid impact, and fluid-structure interaction. The first version to be released will be one- and two-dimensional with extensive plotting capabilities. Future developments will include extension to three dimensions and coupling with shell elements.

The computer code documentation is published in this 4-volume report. If you wish to obtain the STEALTH code for your application, please write: Director, Nuclear Safety and Analysis Dept., Electric Power Research Institute, P. O. Box 10412, Palo Alto, CA 94303. *Science Applications, Inc.*

NP-262 PWR SENSITIVITY TO ALTERATIONS IN THE INTERFACING–SYSTEMS LOCA
Key Phase Report (RP767-1)

One of the important conclusions of the reactor safety study (RSS) was the identification of the interfacing problem between the high-pressure primary system and the low-pressure injection system (LPIS). Because equivalent interfaces exist in all PWRs (although not necessarily with the LPIS), the NRC has suggested three possible "fixes" for future designs, the implication being that each such fix is equally acceptable.

The present analysis of the basic problem shows certain minor limitations in the RSS methodology, demonstrates that the three NRC fixes are not equally acceptable from a risk viewpoint, and that one of the fixes could be implemented in such a way as to yield a worse risk condition than the original design.

As a demonstration of the power inherent in probabilistic methods, an alternate fix and associate test scheme is suggested that reduces the risk to an insignificant level. *Science Applications, Inc.*

NP-263 A SUMMARY OF NUCLEAR POWER PLANT OPERATING EXPERIENCE FOR 1975
Annual Report (RP705-1)

This report provides a summary of operating experience of 56 nuclear plants licensed to operate in 1975. The analysis is based on information and data contained in the 1975 series of Operating Units Status Reports. Additional information was derived from a special survey conducted by EPRI.

Trends in electric energy production are examined from the standpoint of plant size, age, and equipment manufacturer. An attempt has been made to characterize the impact of equipment failures on plant operation. Statistics on outage duration are given for each of the following categories of equipment: valves and piping, reactor internals, turbines and generators, condensers, steam generators, and pumps. *Science Applications, Inc.*

NP-265 ATWS: A REAPPRAISAL; PART II, EVALUATION OF SOCIETAL RISKS DUE TO REACTOR PROTECTION SYSTEM FAILURE; VOLUME I, BWR RISK ANALYSIS
Key Phase Report (RP767)

This document is the first volume of Part II in a series of studies that will examine the basis for the problem of anticipated transients without scram (ATWS).

The purpose of Part II is to evaluate societal risks due to RPS failure based on more current data and methodology than used in WASH-1270. This volume examines and documents the potential contribution to societal risk due to ATWS in the BWR. Volume 2 provides the basis for the calculation and contains a detailed description of the reevaluation and expansion of the RPS fault tree for the WASH-1400 BWR. Volume 3 describes a similar analysis for the PWR.

Theoretical risk studies of this type, where quantified, yield information of two natures. The first gives us an overview of which parts of a complex system (such as a nuclear power plant) may in fact warrant upgrading because they are significant from a risk viewpoint. The present study indicates that ATWS does not warrant backfitting to reduce its risk component because it is less than 5% of the total potential risk. The second yields what can be referred to statistically as prior information. Such information can be used in a Bayesian analysis of data to yield more reliable estimates than would be obtained by using the data alone. *Science Applications, Inc.*

NP-265 ATWS: A REAPPRAISAL, PART II; EVALUATION OF SOCIETAL RISKS DUE TO REACTOR PROTECTION SYSTEM FAILURE, VOLUME 2. BWR FAULT TREE EVALUATION
Key Phase Report (RP767)

This document is the third volume of Part II in a series of studies that examine the basis for the problem of anticipated transients without scram (ATWS).

The purpose of Part II is an evaluation of societal risks due to RPS failure based on more current data and methodology than those used in WASH-1270. This volume examines and documents the potential contribution to societal risk due to ATWS in the PWR. Volumes 1 and 2 described a similar analysis for the BWR.

The results presented in this volume are interesting in several ways. The reactor safety study (WASH-1400) calculated the PWR ATWS potential risk at 0.3% of the total potential risk. An early reevaluation of PWR failure data implied that it should be increased to 1.5%. However a more detailed analysis showed that PWRs comprise two distinct statistical populations as far as single-rod failure probability is concerned and that the PWR ATWS potential risk should increase only to 0.5% of the total risk. *Science Applications, Inc.*

NP-267 SENSOR RESPONSE TIME VERIFICATION
Final Report (RP503-1)

This document is the product of a coordinated EPRI program to develop practical means for verifying sensor response capability in nuclear power plant safety systems. Two related research and development efforts under EPRI sponsorship are being conducted by the University of Tennessee and Babcock & Wilcox Co. Reports from these two project segments will be available under the same EPRI report number when that work is completed.

Nuclear safety systems must respond with sufficient rapidity to ensure that protective actions are initiated before uncontrolled or damaging events occur. To guarantee satisfactory time response capabilities, periodic tests are conducted on a routine basis by nuclear plant personnel. These tests, however, have historically exempted the sensing element from response evaluations because to test them was considered beyond the testing state-of-the-art.

Recent concerns of possible sensor deterioration with concomitant loss in response capability have led to broadened regulatory requirements for periodic surveillance. Response checks must now extend through the entire protection channel, including the sensor element. The lack of an acceptable methodology for determining sensor response capability, short of removal for laboratory test, has been the principal motivating factor for the present work.

This report is intended to provide information necessary for the assembly, test validation, and use of a hydraulic signal generator capable of verifying time responses of pressure and differential pressure transducers in situ. The report is largely self-contained and should permit a utility with modest instrumentation engineering and fabrication capabilities to independently construct a satisfactory test unit. Experimental response time results for typical pressure sensors have been included to confirm prototype signal generator performance. *Nuclear Services Corp.*

NP-44-SR STATUS OF COMMERCIAL NUCLEAR HIGH-LEVEL WASTE DISPOSAL
Special Report

Considerable research and development effort has been expended over the last 20 years on nuclear waste management processes. The work has been reported in a variety of technical reports and journals, generally on a process-by-process basis. This piecemeal reporting makes it difficult to obtain a good overview of nuclear waste technology without a time-consuming review.

In order to understand the status of high-level nuclear waste disposal, a review of available technology was made and reported in this special report. The results of this review, presented in the form of a functional description of a high-level waste management system, show that technology is available to dispose of nuclear waste safely by several processes.

The most attractive alternative in terms of available technology and shortness of time for demonstration at commercial scale is a system that converts the waste to a solid by immobilizing the radioactive elements in a glass matrix. Ultimate disposal would consist of burying this glass product in a deep, dry, stable, geologic structure, such as granite, desert soil, or salt. A detailed discussion of the steps involved in this system are given in this report, together with information on disposal criteria and quantities of waste. Brief comments are also given on international efforts in high-level waste management and advanced disposal concepts. *G. J. Dau and R. F. Williams, EPRI*

SR-46 NUCLEAR UNIT PRODUCTIVITY ANALYSIS
Special Report

An earlier EPRI report examined the prospects for upgrading productivity assessments based on a critical review of operating experience. The review provided both summary and breakdown of data for formal assessment of operational reliability, availability, and productivity. This report, a continuation of the earlier work, extends the assessments through January 1, 1976 and provides elaboration on the components of the performance data.

The productivity of a specific generation unit can be quantitatively assessed on a statistical basis—a task first requiring computation of the inherent productivity of the unit, then modification of this value for productivity decreases, as determined by special transmission system considerations. An extensive discrimination analysis is required to account for modified design features and for changes in operational and regulatory climates. The performance of this discrimination analysis was a primary purpose of this report.

The results of the discrimination study are representative malfunction rates for major, normally operating generation unit subsystems, which can be used to predict unit reliability. Mean time-to-repair data and scheduled outage data are provided to permit conversion of the reliability assessments to availability predictions. Empiric data are provided to permit estimation of capacity factors.

The inherent limitations of the analytic data are indicated by computation of the associated statistical confidence levels. The possibility of expanded usage is provided for by presentation of the outage data as frequency-intensity plots overlaid by probable cause. Finally, the frequency-intensity plots are used to identify those extremely low probability high-outage impact events for which acquisition of statistically valid data cannot reasonably be expected. The use of decision analysis methods to determine appropriate utility actions for these situations is discussed.

The final subject of the report is the modification of current industry-wide data bases that could facilitate productivity analyses. Many contemporary assessments of present data bases recommend extensive expansion of coverage items and cause codes. The recommendations of this report, which are more modest in nature, derive from examining the structure of the outage data and the specific needs of an industrywide data base, which would supplement plant records for productivity evaluations. The influence of information system technology on data base construction is also discussed. *M. E. Lapides, EPRI*

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