The Year 2000: Energy Enough?

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

NUMBER FIVE

JUNE 1976

EPRI JOURNAL is published by the
Electric Power Research Institute.

The Electric Power Research Institute was founded in 1973 by the nation's utilities to develop and carry out a broad, coordinated technology program for improving electric power production, transmission, distribution, and utilization in an environmentally acceptable manner.

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Cover: "Energy enough" is not an abstract calculation. It can be measured in the Btus required to support a broad and desirable range of economic, social, and recreational activities.

EPRI JOURNAL

Volume 1, Number 5 June 1976

R&D STATUS REPORTS

DEPARTMENTS

FFAS Reorganization Meets Changing Needs

When the Fossil Fuel and Advanced Systems Division was established in 1973, division organization reflected our understanding of utility industry requirements at that time. Since then the division has grown to more than 60 employees, with responsibility for a $58 million program in 1976—our grasp of industry problems has expanded and our role in providing solutions has been better defined.

Originally, we absorbed the industry's existing Fossil Fuel Task Force and Committee on Advanced Developments into our advisory structure to work with each of the original departments. Over the past three years, with the formation of division committees, task forces, and program groups, the division has interacted closely with the utility industry and learned firsthand about present and future technology needs. We are particularly appreciative of the dedicated service that our advisory groups have provided during this formative period.

The FFAS division's involvement with other groups, including ERDA, other government bodies, suppliers, education groups, labor, and business, has also shaped our definition of role and responsibility. Close coordination with ERDA, for example, has been essential in ensuring that division efforts and resources were deployed in an optimal manner. As societal influences shifted, the division responded with changes in program emphasis.

Had our original perception held, the original division structure would serve our purposes today. But the industry exists in a changing environment. Our understanding and our role evolved as staff members interacted with the utility industry through the advisory structure and as we began long-range planning for meeting electric energy requirements. It became clear that a change in division structure would increase our effectiveness in planning, implementing, and managing the broad range of technology for which we are responsible. A few examples will illustrate several facets of our reorganization.

There has been an increasing interest in end-use energy utilization and conservation, which has led to the formation of a program on energy utilization and technology. This new program reflects our perception that utilities are concerned not only with increasing the electricity supply but also with using that electricity more efficiently. It recognizes that technical options must be developed so that residential and industrial users of energy can shift from the rapidly shrinking supplies of oil and gas to electricity and that utility load factors must be improved.

Through increased contact with the industry and continuing analysis of future generation options, we also became aware that utilities would benefit from greater efforts to improve performance and reliability of existing fossil-fuel-fired power plants.

The industry has already invested billions of dollars in these plants, and it can be expected to make additional massive investments in similar systems over the next 10–15 years. A greater allocation of our resources in this area could mean significant savings for utilities in the future in terms of fewer outages and less reliance on expensive purchased power to meet system requirements. Under the new organization structure, efforts to improve fossil plant performance and reliability have been consolidated and elevated to program status, with increased funding and staff effort.

Utilities have long been organized on an integrated-systems basis. Our direct contact with the industry has deepened our awareness that power generation and management must be treated as an integrated whole—from fuel source to end use. Thus, under the new structure the division can focus R&D planning and execution on system rather than on component considerations.

In any formal organization, structure can serve to impede innovation or to reflect change, to stimulate progress or to restrict growth. We have chosen to modify our structure not only to accommodate changing R&D priorities but also to permit the most effective use of our most valuable resource—our people—in fulfilling EPRI's objectives of creating, of communicating, and of preparing new technology for commercial application. In this way we hope to aid the electric utility industry in serving the U.S. public as effectively in the next century as it did in the last.

Richard E. Balzhiser, Director
Fossil Fuel and Advanced Systems Division

Authors and Articles

The year 2000. At one time it seemed as distant as a lunar landing or a space rendezvous. Now it is 24 years away—a brief time to plan for meeting the needs of a projected U.S. population of 263 million.

How much energy will we need to keep people fed, employed, and at a decent standard of living? Where will we get it? How do we power society while preserving national security and maintaining a healthy economy and environment? When do we start?

Chauncey Starr, president of EPRI, and many other concerned members of the U.S. energy community are involved in the planning process. The cover feature in this issue, "The Year 2000: Energy Enough?" is based on an EPRI study of electricity needs to the year 2000, which was first discussed publicly in July 1975 when Dr. Starr appeared before the Joint Committee on Atomic Energy of the U.S. Congress to outline "A Strategy for National Electricity Production." The subject was further developed as Dr. Starr spoke before university audiences, community leaders, international energy specialists, and congressional committees. It is now being expanded to serve as the basis of a paper to be given at the World Energy Conference in September 1977 in Istanbul.

The JOURNAL article, which begins on page 6, discusses the links between energy, employment, and the GNP. It lays out a range of choices that society may make in goal targeting, resource management, and timing of energy policy considerations for the future. And it suggests the combination of choices most likely to yield success.

Starr

Anderson

□ Planning for the future is also a theme in this month's program feature (page 14) by P. M. Anderson, program manager for System Planning, Security, and Control. In authorizing large capital expenditures today for tomorrow's power systems, utilities must make decisions despite many future uncertainties: cost and availability of fuel, regulatory requirements, reliability of lines and generators. EPRI's System Planning, Security, and Control Program has among its objectives the development of techniques to aid utility system planners in predicting future trends and thus contributing to the orderly growth, control, and cost-effectiveness of utility networks.

As program manager, Anderson oversees this effort. He came to EPRI in 1975 from Iowa State University, where he was a professor of electrical engineering. Anderson earned his BS, MS, and PhD in electrical engineering at Iowa State and taught there for 20 years. While on the faculty, he was involved in power research and helped to launch a power system computer service to assist the power industry in computer solutions of large electric network problems. On leave from Iowa State, Anderson spent a year with Pacific Gas and Electric Co. in San Francisco in 1971–1972, researching power plant dynamic modeling.

□ A problem that causes loss of plant availability and increased personnel exposure to radiation is discussed in "Corrosion Damage in Nuclear Steam Generators" (page 20). The author, Louis J. Martel, is manager of an EPRI program to develop technologies for the reduction and control of corrosion damage to steam generators. Martel discusses the corrosion process and the efforts to combat it in this month's technical feature.

Martel

Young

Gens

Lou Martel came to EPRI in 1974 after an 18-year career with General Electric Co. He joined GE as a materials engineer in the Small Aircraft Engine Department in 1956 and was assigned to the Knolls Atomic Power Laboratory in Schenectady, New York, in 1957. There he served as engineer, supervisor, and manager.

Martel earned his BS in metallurgy at the Massachusetts Institute of Technology and his MS in metallurgy engineering at Rensselaer Polytechnic Institute. He is now program manager of System Materials in the Nuclear Power Division.

□ As an added feature in the JOURNAL this month, Frank Young, manager of the AC and DC Overhead Lines Program, and Ralph Gens, a member of the Transmission and Distribution Division Committee, discuss highlights of their April trip to the Soviet Union as members of a U.S. delegation to a symposium on dc transmission.

Young and Gens both serve on the U.S.–USSR Joint Commission on Scientific and Technical Cooperation as members of the project group on UHV Transmission Technology and HVDC Transmission System Experiment Design. The commission was set up in 1973 to facilitate the exchange of technical information between the two countries in such areas as energy research, agriculture, and medicine. One of the results of its efforts in space technology was the Apollo-Soyuz lunar mission in 1975.

In 1974 Frank Young came to EPRI on loan from Westinghouse Electric Corp., where he was manager of research projects. He received his BSEE from Stanford University in 1955, joined Westinghouse the same year, and earned an MSEE from the University of Pittsburgh in 1962. Young joined EPRI as a permanent staff member in 1975.

Ralph Gens serves as manager of Planning, Research, and Development of the Bonneville Power Administration in Portland, Oregon. Gens received his BSEE from Oregon State University and joined the BPA in 1948. He became a Fellow of the IEEE in 1969 and has been a member of the T&D Division Committee since the formation of EPRI.

□ Beginning this month the JOURNAL will publish a series of profiles of EPRI Advisory Council members. In this issue Arthur C. Stern, chairman of the Council for 1975–1976, is interviewed.

Next month's JOURNAL will be a combined July/August issue.

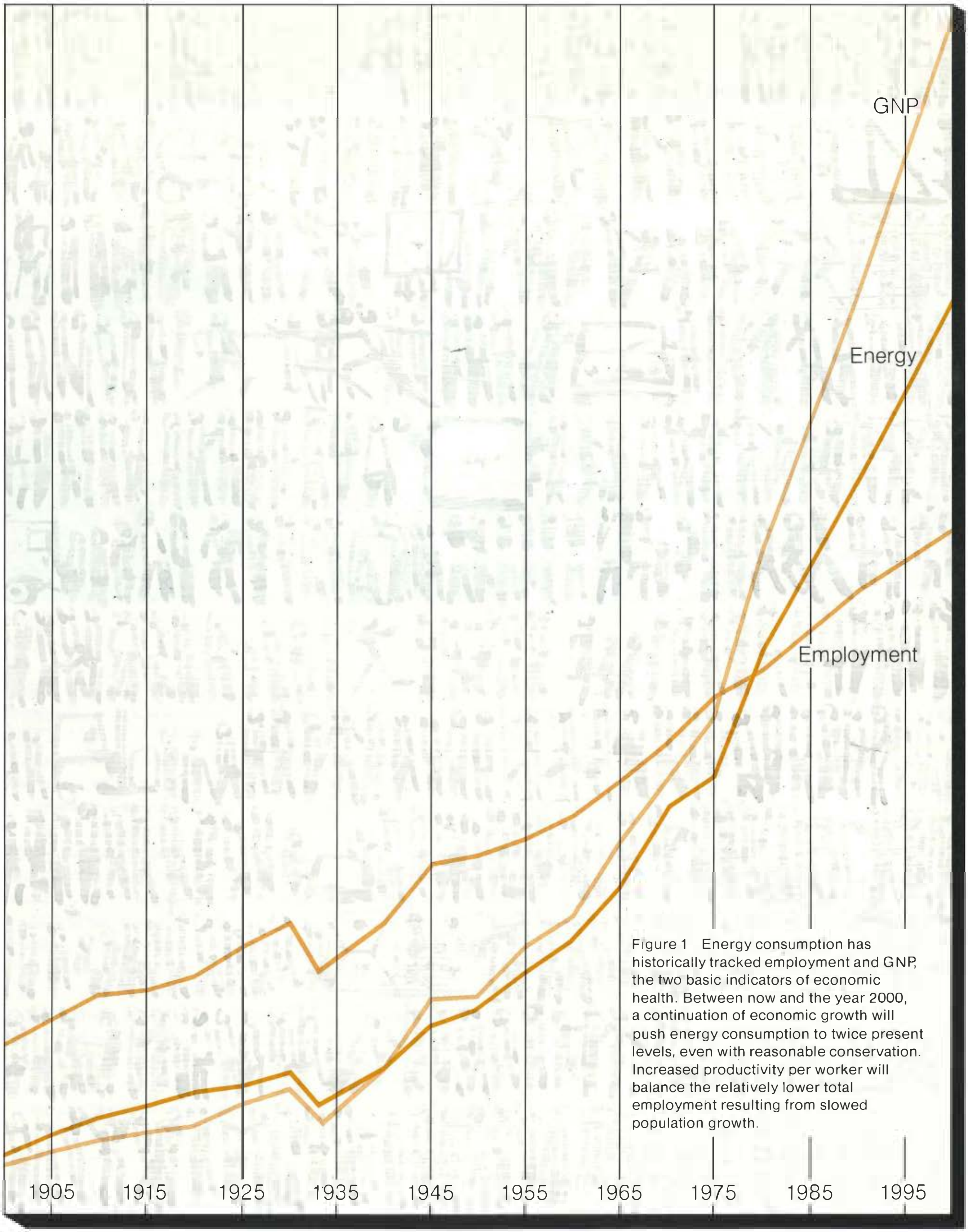


Figure 1 Energy consumption has historically tracked employment and GNP, the two basic indicators of economic health. Between now and the year 2000, a continuation of economic growth will push energy consumption to twice present levels, even with reasonable conservation. Increased productivity per worker will balance the relatively lower total employment resulting from slowed population growth.

The Year 2000: Energy Enough?

by Chauncey Starr

National growth may be stunted unless already-strained energy supplies can be more than doubled by the year 2000. Major reliance on foreign oil would be imprudent. New technology can eventually help, but electricity generated from coal and uranium will have to assume the chief role in making such energy expansion possible.

Chauncey Starr is president of the Electric Power Research Institute.

The year was 1922. Eugene Davenport, dean of the Illinois College of Agriculture, had just sounded an alarm in the pages of *Scientific American*. The people of the U.S., he predicted, would soon face "hunger, and even famine" if action were not taken immediately to boost food production.

Food supply was falling behind population growth and consequent demand. The U.S., in Davenport's words, was "rapidly slipping into the class of food-importing nations. . . . Unless we are able to reverse the tide," he warned, "we must readjust our social, economic, and industrial organizations to accord with this new condition."

Today's predictions of shortages echo the urgency of Davenport's warning. Only today it is energy starvation, not want of food, that many observers see as a blight on the nation's future.

The 1920s witnessed a crash program of agricultural expansion, aided by new technology on farms and in factories, that multiplied food production and averted the threatened crisis. So successful was the effort that the U.S. today exports food to much of the rest of the world, in addition to feeding its own 215 million people. The parallel is encouraging, but the question remains: Will the U.S. be similarly successful in mustering resources to feed the nation's large and growing needs for energy?

The answer to this question will be determined largely by decisions made in three critical areas: goal targeting, resource management, and timing. What follows is an attempt to outline some alternative approaches and to suggest a mixture most likely to yield success.

Fixing the target

How much energy will we need in the year 2000? Two indicators give us a good idea: our anticipated standard of living and the size of our future labor force.

Historically, energy consumption and prosperity rise and fall together. A strong appetite for energy marks those periods when employment is healthy and the economy is growing. Energy consumption falls with waning employment and a sagging national economy.

The gross national product (GNP), because it measures the vast array of goods and services that are turned out by the U.S. economy in any given year, mirrors living standards. The links that exist between energy, employment, and GNP (Figure 1) provide a method for predicting future energy needs. If we know roughly the number of people working at some future date and the quantity of goods and services they need to produce, we can make a reasonable estimate of the energy supplies required to support production.

Fixing an energy target by this method inevitably touches on certain issues of broad economic and social policy. Most conspicuous is the growth issue. Are we ready to settle back and accept a no-growth economy, or do we want to push for the steadily increasing levels of goods and services that will be necessary to lift millions of Americans to a standard of living many consider minimally desirable? A no-growth economy—with a drastic change in mass social aspirations—should not be allowed to occur as an unconscious and unintended by-product of energy shortages.

The targeting analysis that follows focuses on this possibility and an alternative—continuing growth at an appropriate rate.

Quantifying prosperity

The historical growth rate of the U.S. economy over the period 1955–1975 averaged 3.5% per year in constant dollars. Accompanying this expansion was a swelling work force. The Bureau of Labor Statistics predicts a civilian work force of 113 million by the year 2000, up from about 85 million today. Almost all this labor force is born by now, so future birthrates can have very little effect on its size. Based on experience, how much energy will it take to support the output of a work force this size?

The answer—taking into account potential changes in energy availability, technology, environmental costs, *and conservation*—comes to about 150 quads (1 quad = 1 quadrillion Btu), with an uncertainty of ±10%. Historical growth would project 170 quads, conservation might save about 20%, and environmental costs may add about 10%—leading to a probable 150 quads (Figure 2). This figure—which is twice our present national energy consumption—is the estimated amount of energy we will need in the year 2000 if the economy continues to grow as it has and as many think it must for the benefit of all segments of our population.

Figure 2 Continuing the nation's historical growth trend will require far more energy than the no-growth option, which would freeze socioeconomic progress at roughly current levels (represented here by 1973 data). **A** pinpoints an energy demand of 170 quads for the year 2000, based on historical growth. **B** indicates a downward modification to allow for conservation savings of 20% and environmental costs of 10%. **C**, falling well below **A** and **B**, shows what the projected level of energy demand would be in the year 2000 if the no-growth option is chosen. **D** indicates what the no-growth option would have resulted in had it been followed from 1948 until 1970.

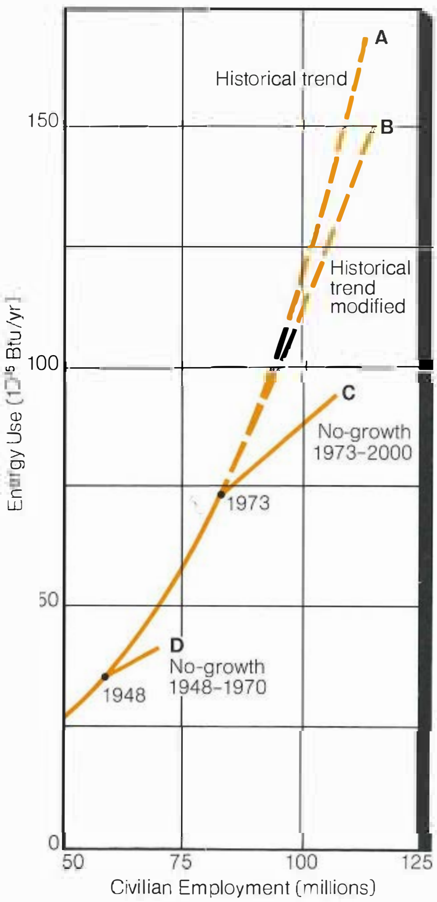
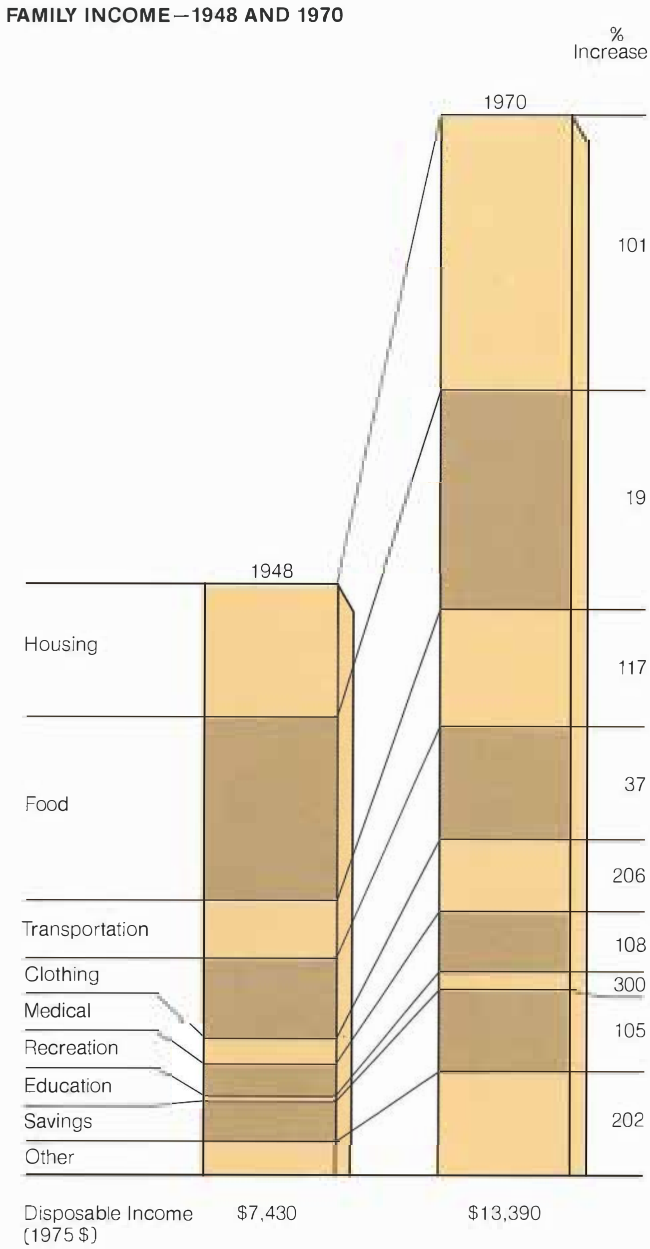


Figure 3 Between 1948 and 1970, disposable family income nearly doubled in real purchasing power. Consumers were able to buy more—especially in areas such as recreation and education—and still increase their savings. Americans thus enjoyed substantial growth in economic well-being during this period.



No growth?

A no-growth situation would freeze the ratio of employment to energy use at its present level—that is, keep fixed the energy consumed per employed worker and fix the mix of industrial, commercial, domestic, recreational, and other energy-related activities. Freezing this employment-energy ratio would be tantamount to maintaining all major social and economic patterns, only replicating this mix in the future to accommodate an increased labor force.

What this no-growth option would really mean becomes clearer if we compare the nation's actual experience in the year 1970 with what 1970 would have been like had our technology and economic productivity been frozen shortly after World War II—say, in 1948.

The no-growth scenario would replicate the 1948 economy in an expanded form for a population that had grown from 147 to 205 million. In this hypothetical situation, the social structure and economic mix for 1970 would have been the same as those that existed in 1948. These have been described in the U.S. Dept. of Commerce's monumental study, *Social Indicators 1973.* Thus, the actual changes that did occur between 1948 and 1970 can be considered a measure of the effect of increased productivity per worker, associated with increased energy input into the economy. (It is important to recognize that increased productivity per worker is the result of technological development of energy-converting machinery that can produce more goods and services, so that increased productivity generally brings with it increased energy need per unit of output.)

Actual energy use in 1970 totaled 68 quads, as compared with what might have been a 1970 level of only 41 quads under such no-growth conditions. That is, the 1970 work force could have been supported with an energy input 60% as large as was actually used if the nation had been willing to live in 1970 as it did in 1948. What, then, did the nation get in return for this actual 1.66 multiplication of energy consumption per employed worker between 1948 and 1970?

A glance at Figure 3 shows that the consumer's paycheck actually bought much more in 1970 than it did in 1948, reflecting a substantial rise in the U.S. standard of living. A 66% increase in energy consumption per employed worker supported a 90% increase in real family income. The percentage of personal income required to furnish necessities such as food and clothing declined, whereas purchases in discretionary areas such as medical care, education, and recreation increased substantially. The rise in mean family income moved a fifth of the population out of the poverty bracket to a level above the threshold of acceptable nutrition and housing.

These economic changes triggered a profound social impact as well. One example was the massive entry of women into the work force. This entry was no doubt hastened by new labor-saving devices for the home and the increased use of office and factory machinery that could be operated by brains rather than brawn. Had the percentage of women in the work force been frozen at the 1948 level (28%, as compared to the 1970 actual of 38%), 7.8 million fewer women would have held paying jobs in 1970.

The year 1970, then, would have looked quite different had we opted for a no-growth economy in 1948. But does the same logic apply to a growth versus no-growth decision in 1976? What about the contention that today, in contrast to 1948, we have all the labor-savers we can possibly use?

Granted, most of us are capable of brushing our teeth, opening a can of soup, or carving a turkey without the aid of energy-consuming devices. It is quite another matter, though, to reject historical and more substantial benefits of increased use of capital- and energy-intensive machine production per U.S. worker: more employment, less poverty, better health, more education, better housing, and more recreation. These benefits are by no means trivial, and an aware public is not likely to accept less if it does not have to—especially while the lowest-income fifth of our population remains below the acceptable level of housing, nutrition, and personal welfare.

For the foreseeable future, then, we will likely keep shooting for the historical increase in national prosperity, with an energy target in the year 2000 that is large enough to accommodate this goal. Any smaller target would necessarily place stunting restraints on our options for social progress.

Switching fuels

The second major area of choice in fixing our energy capabilities for the year 2000 involves management of fuel resources. How can we reduce our dependence on foreign oil? Should a greater percentage of our national resources be converted to electricity? What are the best choices for fuel conservation? Can new power sources help? All these questions will have a bearing on our ability to meet our energy needs by the century's end.

To see what a staggering increase the target figure represents, consider the nation's level of energy consumption in 1973. Total fuel consumption in that year was 75 quads, just about half of what will be required in the year 2000. Of those 75 quads, there were 35 quads of oil, 23 quads of natural gas, 13 quads of coal, 3 quads equivalent of hydro, and 1 quad equivalent of nuclear. The picture, then, in 1973—and one that still applies today—is of an economy heavily dependent on oil and gas to meet its fuel needs.

This picture is destined to change. Availability and cost problems with foreign oil and gas dictate that the increase in energy consumption be fueled by other sources. Alternatively, our national vulnerability to foreign intervention in U.S. policies will increase if we become more dependent on foreign oil. The most feasible indigenous alternatives for such large-scale increase over the next quarter century are coal and uranium, both of which are available domestically. Even if oil and gas supplies can be maintained at present levels (at best a gamble) and hydro also increases slightly, coal and nuclear capabilities must grow from a combined total of 14 quads to 85 quads by the year 2000. This represents an increase of about six times today's level for this pair.

The focus on coal and uranium as our major fuels has definite consequences for the form in which most energy will be delivered. Specifically, the increased use of coal and uranium points to increased electrification.

Electric power plants will be the only substantial means for converting coal into usable energy by the year 2000. The manufacture of synthetic oil and gas from coal, potentially a very important development, will not yet have had the opportunity to make a sizable commercial impact. Even if such conversion processes become commercial in the 1980s, they can meet only a small fraction of national needs by the year 2000 because of construction lead time. And nuclear energy from uranium can be utilized only when converted to electricity.

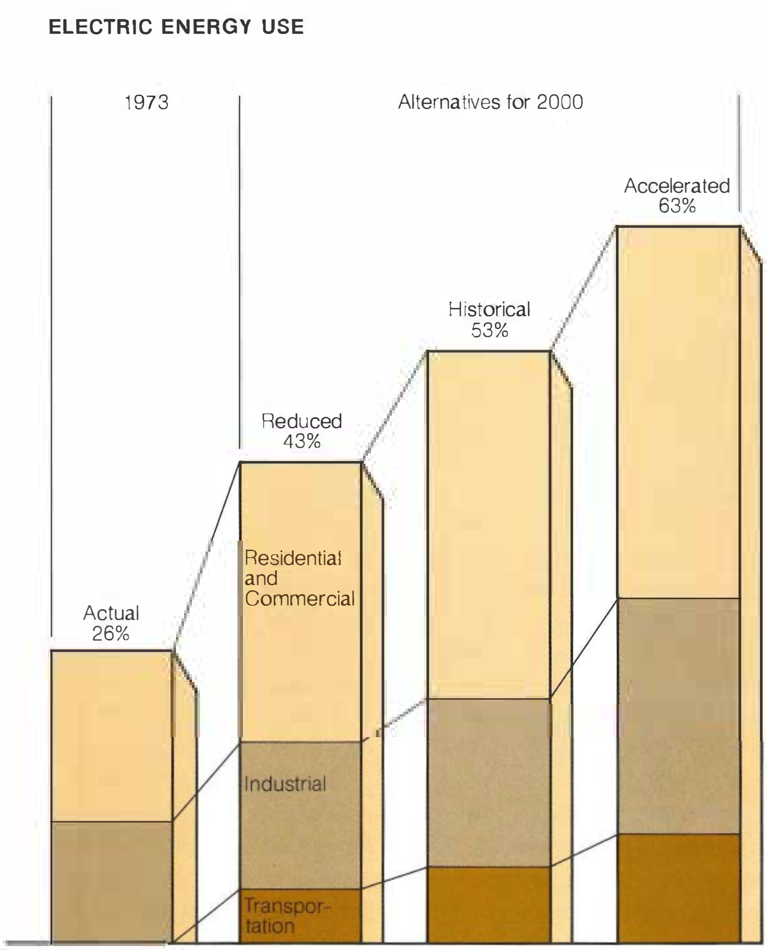
In 1973, the fraction of the nation's primary energy that was converted to electricity was 26.4%. For some time that fraction had been growing steadily. During the years 1950–1970, the electric fraction of primary energy use grew at a compound annual rate of 2.63%. Extended to the year 2000, this rate of fractional increase yields a primary fuel fraction of 53%. In other words, if present trends continue, by century's end about 53% of all our primary energy resources will be converted to the form of electricity.

Because many uncertainties affect this figure, it would be best for planning purposes to sketch a range of possible outcomes—say 10%, give or take in either direction. Figure 4 shows how the resultant alternatives (a range of 43–63%) would impact the various energy-using sectors of the national economy.

The first alternative (43% electrification) presented in Figure 4 assumes only modest growth in the electricity-using fraction. Space heating, water heating, and cooking would still be handled mostly by oil and natural gas, although an increasing array of labor-saving devices and appliances for the home would run on electricity. More urban mass transit systems would switch to electricity, but the use of electric cars in the year 2000 would still be quite limited.

The second alternative in Figure 4, and the one most likely to occur, assumes greater technological change and consequent increases in the use of electricity. The outcome represented by the third alternative assumes an accelerated conversion to electricity stimulated by severe shortages of oil and gas.

Figure 4 The industrial sector is the nation's main consumer of energy, followed closely by the residential and commercial sectors. Residences and commercial enterprises, however, are the main users of that percentage of total energy delivered in the form of electricity. Shown here are the percentage of total energy used by the electric fraction and three alternatives for the growth of that fraction.



The efficiency push

The campaign to slash the nation's future energy consumption hinges on two strategies: decreasing use and increasing efficiency. Reducing end-use activities is basically a social option, implying a change in lifestyles. Getting more end use out of available energy resources is a technical challenge, focused on ways energy might be better harnessed and stored to perform various tasks, such as driving machinery, generating heat, or providing light. The emphasis here will be on technical improvements as a means of yielding energy savings without sacrificing our end-use options. The goal is doing better—not doing without.

The potential savings of both electric and nonelectric energy stemming from conservation efforts range from none to 40%. As most conservation requires a capital investment in more efficient equipment, the extreme technical limits are unlikely to be achieved. The middle value (20%) is thus more reasonable as a planning target. These estimates reflect the result of actions that can be taken now (e.g., better insulation of residences, installation of already developed energy-saving devices over the next 5–10 years, and introduction of foreseeable new technology over the next 25 years).

The gradual savings accumulated in this manner should add up to an impressive 20% or so by the year 2000. Actual savings will more likely occur sooner in the electric than in the nonelectric sector, despite the greater potential in the latter, because the technology of conservation is more easily applied to electric uses and because the conservation effort can be centralized in the technical aspects of large power systems and in the manufacturer's design of mass-produced equipment. In contrast, the insulation of homes, for example, involves many individual decisions.

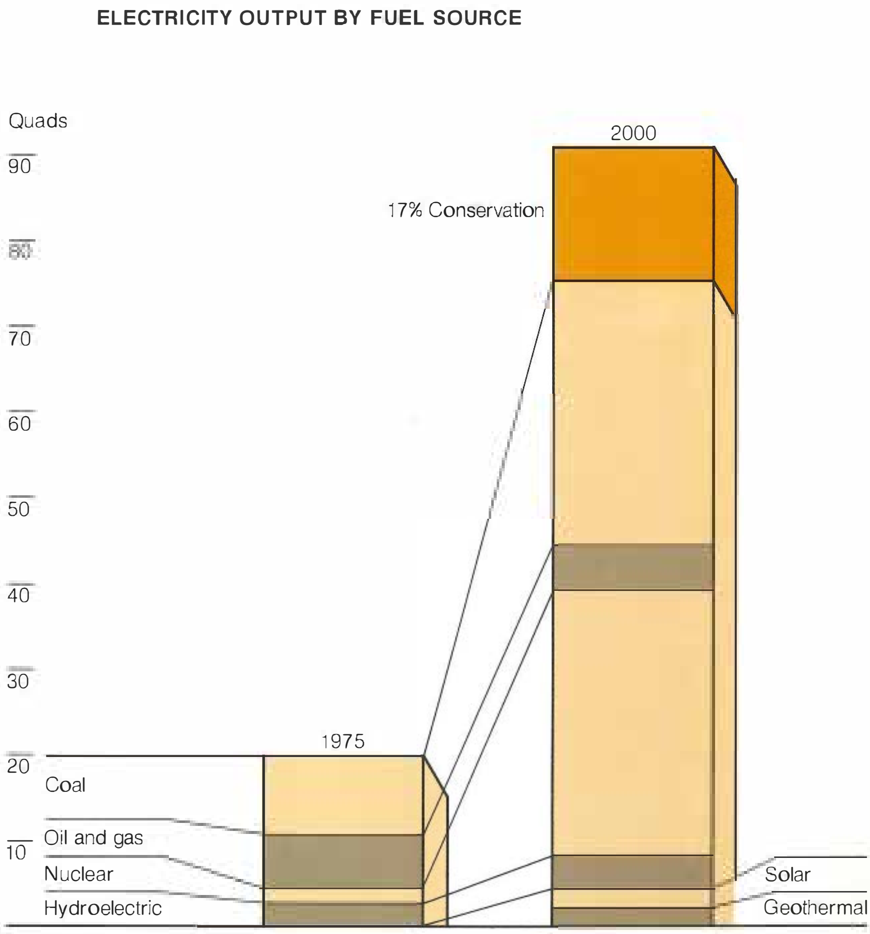
Solar and geothermal

New energy sources that could conceivably help out by the year 2000 are but two: solar and geothermal. Except for dry steam geothermal (a very scarce resource), these are not yet at the stage commercially that would permit a meaningful estimate of their growth.

Solar's main contribution during the next quarter century will be in heating new homes and commercial buildings. Solar energy converted to electricity is not likely to be available at all on a commercial scale during this period. And the availability of geothermal electricity is a gamble because of engineering and hydrothermal resource issues.

Probable sources of electricity for the year 2000 are shown in Figure 5. Included are the fairly optimistic estimates of solar and geothermal contributions projected by ERDA. Even with these hopeful estimates, coal and nuclear power must still provide about 80% of the electricity generated. No foreseeable technology can substantially alter this outlook.

Figure 5 The swing to electricity between now and the year 2000 will result in a requirement for 90 quads of electric output if historical usage patterns hold. But 15 quads of that total can be eliminated by using the electricity more efficiently. That saving amounts to three-fourths of the electricity consumed in the U.S. in 1975. Still, a vastly expanded coal and nuclear power capacity will need to be in place to meet the almost quadrupled electricity requirement that will remain.



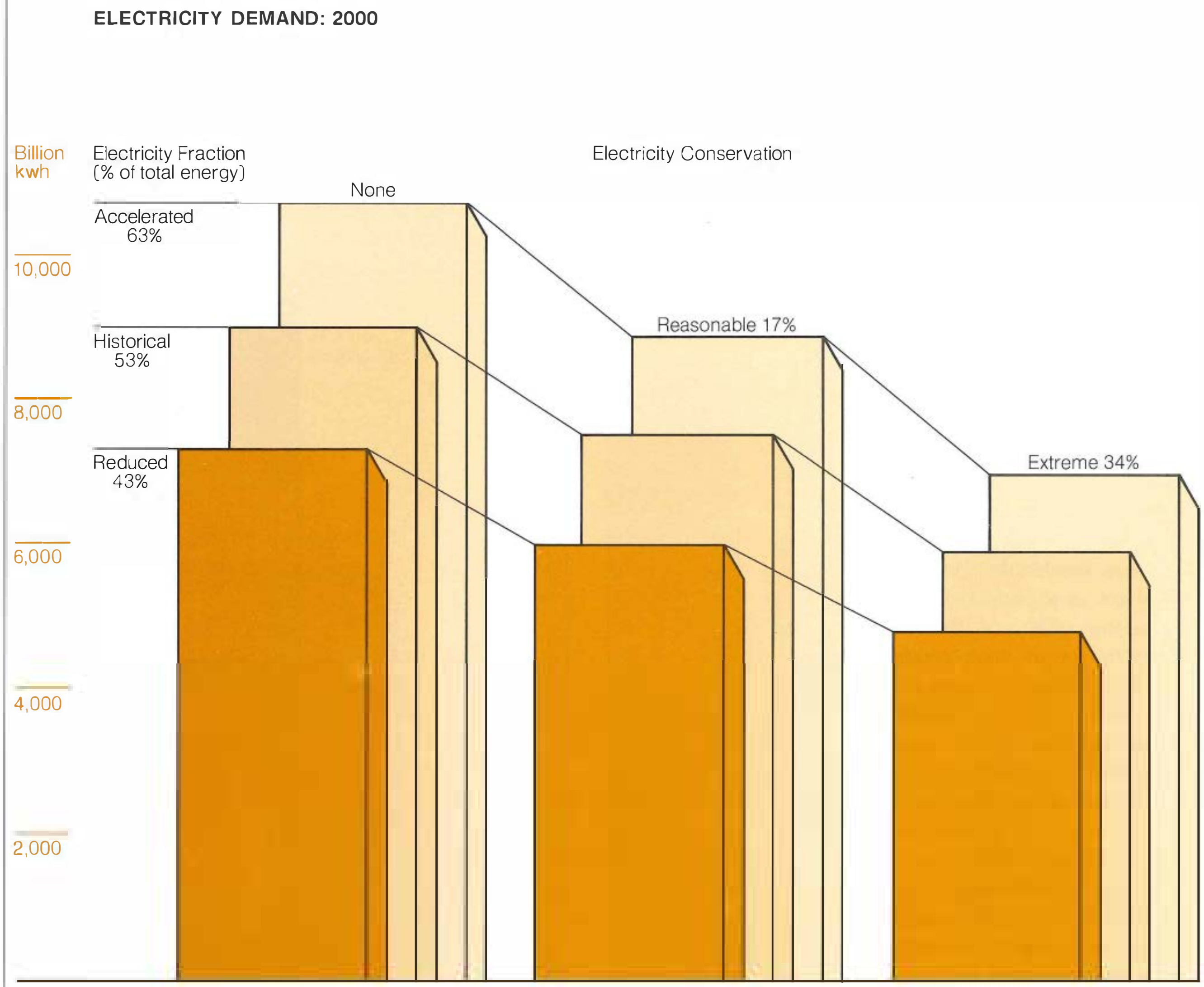
Environmental costs

Protecting or improving the environment while meeting energy needs will generally mean additional energy costs. We must expect to pay such costs, and our estimates of future resource needs should take them into account.

Consider, for example, the decrease in conversion efficiency of conventional power stations caused by the switch from water-cooled to air-cooled condensers (a measure designed to reduce ecological effects on water resources). Owing to the higher temperature of the steam cycle condenser with air cooling, fuel consumption rises about 6–10% for fossil-fuel-fired plants and 7–13% for nuclear plants. In addition, because the air-cooled system costs more to begin with, there is a 10–15% increase in capital investment per unit output.

More familiar is the case of car antipollution devices, which, as most motorists now know, can ruin even the most diligent efforts to save on gasoline mileage. Or again, placing elec-

Figure 6 With a reasonable conservation program and with electricity supplying 53% of our total energy requirements, the U.S. will need nearly 7500 billion kilowatt hours for the year 2000 in order to sustain national growth at historical levels. If conservation efforts fail, the target will have to be adjusted upward to a figure closer to 10,000 billion kilowatt hours.



tricity distribution apparatus underground can save the landscape, but it increases capital and material costs substantially. Conservation by increased efficiency may more than compensate for the costs of meeting environmental objectives, but the net savings may be only half what could be achieved by conservation alone.

Net capability

Taking the fuel resource picture as a whole, then, it seems that the best avenues toward ensuring our national future supply are increased electrification and increased conservation through greater efficiency. Figure 6 shows how these factors translate into a range of targets for future electricity production.

Each estimate of electricity demand, based on the total projected energy need for the year 2000, is a function of two factors: the fraction of total energy that is likely to be supplied in the form of electricity and the amount of energy saved through conservation efforts. Without conservation, total national need by the year 2000 is 170 quads. If 53% of this energy is converted to electricity, 9000 billion kilowatt hours would be the result. If we assume 53% and reasonable success in conservation—the combination of circumstances most likely to occur—then the target figure becomes roughly 7500 billion kilowatt hours for the year 2000, about 3.8 times present electricity production.

If a reasonable level of conservation is applied to all energy use, and environmental costs are added, we would expect a total energy consumption target of 150 quads. This is consistent with our electricity production target of 7500 billion kilowatt hours.

Acting now

Timing is the third critical area of decision making that affects future energy supply.

Very long lead times are required to bring about a change in the national energy mix. Historically, it has taken from 30 to 50 years for new processes to make a substantial impact on energy supplies. As we have seen, it is already too late for new power sources, such as solar and geothermal, to make more than very small and scattered inroads before the century's end.

Because electricity is the one energy source that is commercially viable today and is likely to have the fuel necessary for rapid growth over the next 25 years, electricity is the logical choice for action. Massive expansion of electric power capabilities cannot wait if the industry is to be responsible for providing at least 7500 billion kilowatt hours of usable energy by the year 2000. And this is only a minimum target. If conservation efforts fall short, we will need even more to avoid being trapped in an energy stranglehold by the oil-producing nations.

But what about overexpansion? How can we know that all this added capacity will really be needed? Perhaps relations with the oil-producing nations will change for the better. Perhaps unforeseen events will fatten our oil reserves. Perhaps vast new deposits of oil will be discovered.

Perhaps so. But none of these possibilities alters the need to act now. Considering the time it takes to get new electric generating facilities on line, there will be plenty of opportunity to change course should the circumstances warrant. Raising capital appears to be no serious obstacle. At worst, we may have surplus generating capacity for a while until demand catches up. Such a situation would surely not last long in view of the nation's vigorous appetite for energy.

The alternative to immediate action is to delay and risk energy starvation. If we expand too quickly today, we can slow down tomorrow. But if we delay now, we will have no recourse.

Can we meet the test?

Clearly, maintaining the level of economic growth that Americans have come to regard as natural will be no easy task over the next quarter century. Feeding the machinery of progress will require a steady diet of energy.

It is clear, too, that our fuel sources will have to change in order to meet that need. Continued reliance on foreign fuel creates hazards in terms of national security, balance of payments, and unforeseeable costs. The prudent choice is to rely instead on native coal and uranium for conversion to electricity. Accompanying this fuel switch and the resultant growth of the electric fraction will be a vigorous campaign to boost efficiency in energy use. Such conservation technology is as important as supply technology.

Current estimates suggest that we should begin now pushing toward a national electricity target of at least 7500 billion kilowatt hours for the year 2000. Meeting such a target will require almost four times our present electricity supply, at a growth rate of about 5.7% per year. And this target assumes reasonable conservation measures. If such measures fail, then we will need, as Figure 6 shows, a supply more in the neighborhood of 9000–10,000 billion kilowatt hours.

The most cautious choice at this time, if the least optimistic, would be to shoot for the larger target, but the required expansion is so large that it makes little difference in our current national efforts if we plan for 7500 or 10,000 billion kilowatt hours.

Hopefully, today's energy supply problem will one day be as obsolete as the threatened food crisis of 1922. Something to bear in mind, though, is that the food crisis was resolved in large part by foresight, technological drive, and a national recognition of the need to act. Everyone understood the need for food—but how many now understand the need for energy?

Power Systems: Planning and Operation

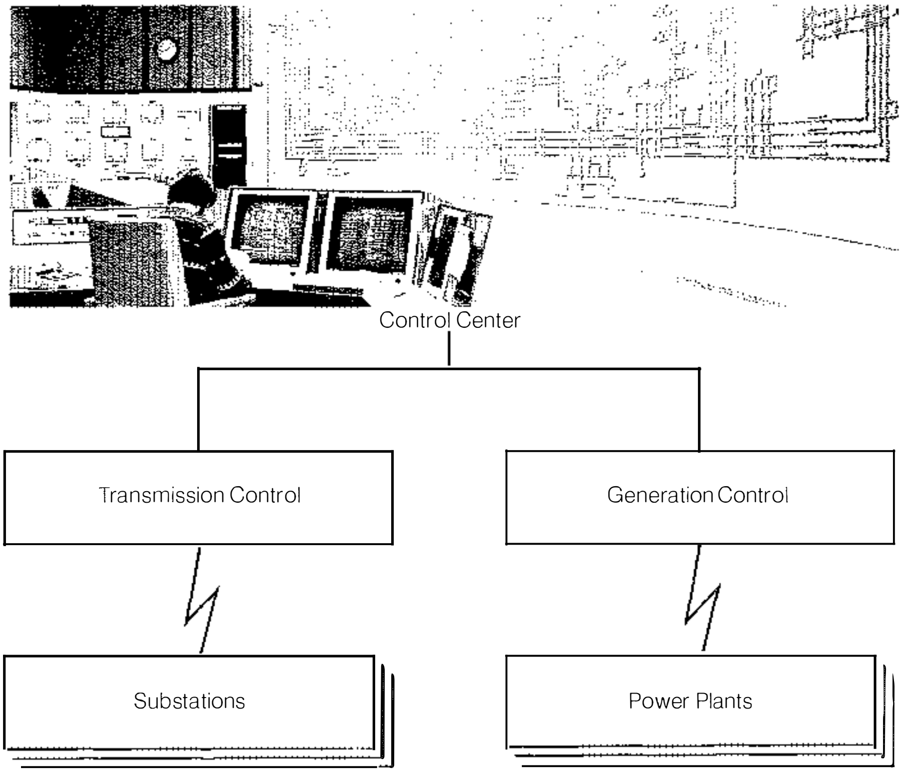
Load forecasting is only the tip of the iceberg as utilities deal with the cost implications of ever larger generating units, the advent of new technologies, and the need to maintain—or improve—reliability through pooled interconnections. □ An EPRI program article

by P. M. Anderson

Early in the century, utility systems in the United States operated, for the most part, as isolated islands, each containing small clusters of load and generation. The interconnection of these islands by transmission lines was begun in the 1920s, and the trend toward increasing interutility tie-line capacity continues to the present, with good reason. Interconnections improve system reliability because a loss of major generation or transmission facilities can be offset by immediate aid from neighboring systems. Economic purchase and sale of energy can be negotiated quickly and easily on an interconnected network. Bulk purchases can be arranged to allow deferral of expensive future facilities, thereby permitting better long-term financial planning.

Another advantage of interconnected operation is the economy of scale. Large generating units of similar design have a lower unit cost ($/kW of installed capacity) than small units. This has tended to favor the installation of the largest possible units on a given system and has even encouraged joint ownership of large, efficient units.

Because of these advantages, the North American utility network has continued to expand and strengthen integrated systems over the past 50 years. At present, almost all the regions of North America north of the U.S.–Mexican border are operated as part of some interconnected system. In the U.S., the systems are separated into three large interconnected networks that can be roughly divided as



Factors Overriding Economic Considerations

Public safety
Loading limits
Natural disasters
Load characteristics
Security constraints

Factors Affecting Economy

Network loading
Load management

Factors Overriding Economic Considerations

Generation limits
Transmission limits
Reserve requirements
Environmental factors
Hydro conditions
Load characteristics
Security constraints

Factors Affecting Economy

Availability of fuel
Cost of fuel
Plant efficiency
Load management
Control sensitivity
Energy purchase

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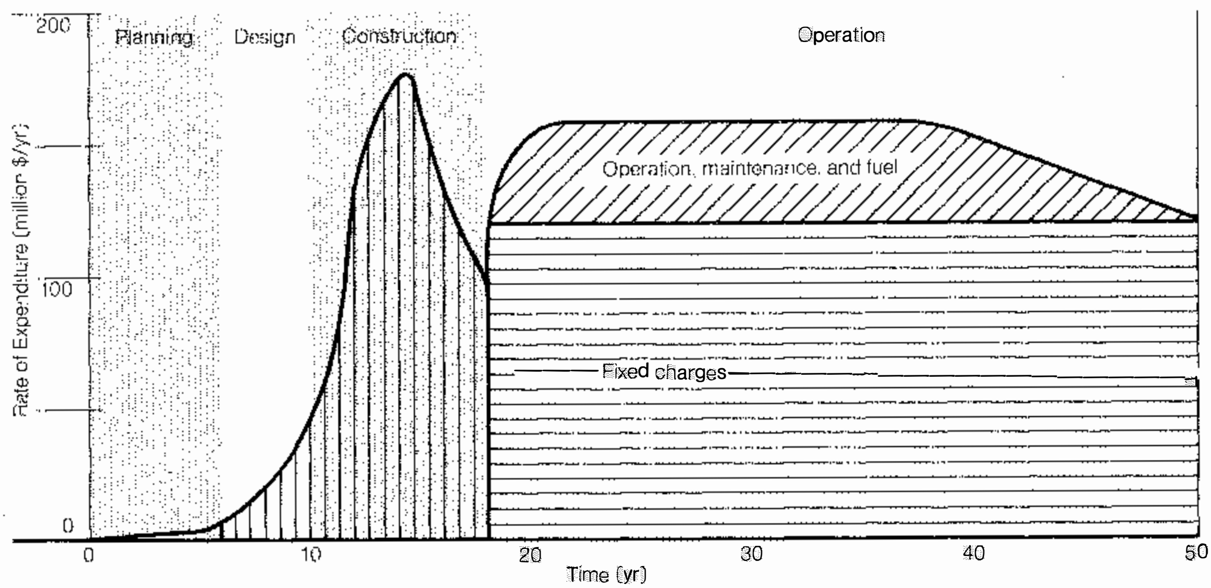
EXPENDITURE COMMITMENT FOR A 1000-MWe PLANT

Consider the proposed construction of a 1000-MWe power plant. Assume the following for plant construction and operation. Using these figures, a projection of expenditures for this plant can be plotted.

Capital costs	$800/kW
Operating costs (annual)	
Operation, maintenance, and fuel	7.5 mills/kWh
Fixed charges	20 mills/kWh
Average plant factor (annual)	70%
Construction time	8 years
Useful life	30 years

(Source: *Electrical World*, November 15, 1975.)

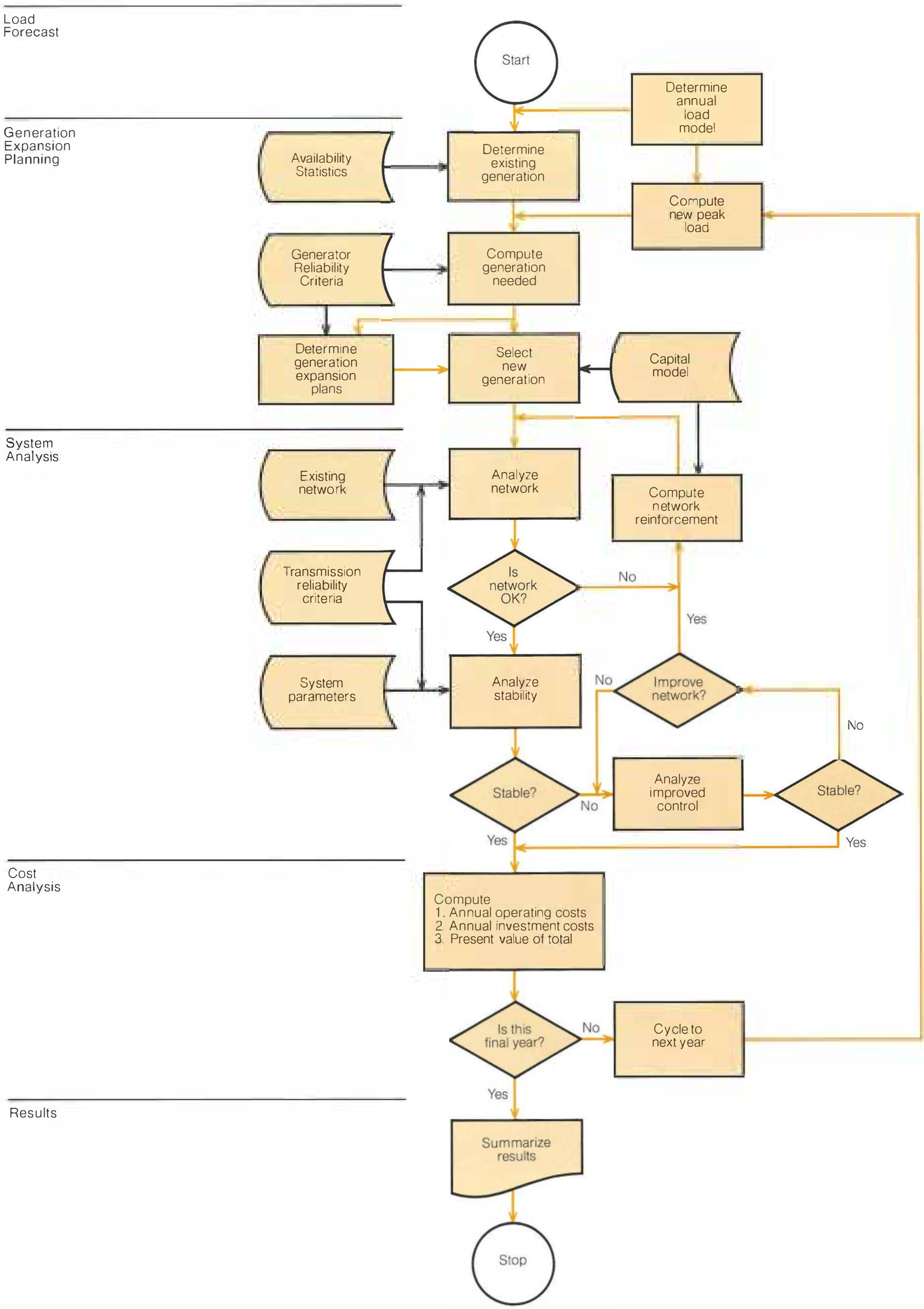


The area under the curve presents the total expenditure for planning, design, construction, and operation. This simple sketch demonstrates vividly the tremendous leverage of system planning. The planner commits not only the construction of the plant but also the 30 years of fixed charges.

Suppose that through astute planning this project could be deferred by one year. This amounts to the deferral of roughly $100 million, or a savings of about $15–$20 million in fixed charges. Multiplying this amount by the 10 to 15 such plants to be added *each year* during the coming decade gives a measure of the importance of system planning.

The impact of system operations is also evident from the curve. Any savings in fuel, for example, reduces the area ($) for that part of the graph.

One of the important tools of the power systems planned is the computer, which is used for simulation and analysis. The flow chart shows a typical sequence of planning simulations, from generation and transmission planning through cost analysis. These simulations are used to eliminate the infeasible solutions, thereby concentrating the design effort on a small group of workable system expansions.



eastern and western, with Texas the third system. Experience has shown that these large networks are not only economical but remarkably secure—that is, inherently resistant to failure by cascading outage events. This is due to the generally high reliability of electric equipment, the stability of the system controls, and the care and conservatism in system design.

It should not be inferred, however, that there are no problems with today's interconnected system operation or with the planning of future systems. Experience has shown that the new, large generating units tend to be less reliable than smaller units. This is partly due to the greater complexity of these units and partly due to the immaturity of the newer designs. The same tendency toward lower reliability has been noted in the higher-voltage transmission and substation apparatus of recent years.

Coordination of regional planning and operations

The blackout of November 1965 in the northeast came as a severe shock to the utility community. This event, or rather chain reaction of events, indicated that the design and operating practices for interconnected systems needed careful industrywide scrutiny. It was clear that a coordinated regional approach was necessary to develop acceptable standards of reliability for the interconnected, interdependent groups of utilities. Thus the National Electric Reliability Council (NERC) was established.

NERC divided the U.S. and portions of Canada into nine large operating regions. Each region has unique features in load density, miles of transmission lines, numbers of generating plants, and climatic conditions that provide a factual framework for specifying reliability standards for that region. These standards provide a common design level and tend to equalize the cost of reliability assurance among the cooperating utilities. Experience has tended to validate this system as providing a high level of reliability at an acceptable cost.

System operation has also been standardized and is coordinated through another national organization, the North American Power Systems Interconnection Committee (NAPSIC), which coordinates operating and control practices among the interconnected utilities to ensure fair, effective operating practices.

EPRI's approach

EPRI's System Planning, Security, and Control Program is concerned with bulk power system long-range development, and system operation or control. The term *bulk power system* refers to large-scale energy conversion and transport systems, usually power plants and electric transmission lines, and possibly fuel resources and transport alternatives as well.

Planning, or development, covers the definition, evaluation, and timing of all future bulk power facilities needed to provide electric energy. This includes consideration of all feasible alternatives in generation and transmission. The planning process involves system reliability or standards of service, construction and operating costs, ecology, and the environmental impact of future activities. It is constrained by regulatory policy, economics, operational limitations, and the availability of resources.

Security and control, or bulk power system operation, refers to the centralized control of the operating condition of an entire area, usually a single utility or power pool. (Some utilities use the term *dispatch* for this function.) Its objective is to produce the required amount of electric energy with a satisfactory quality of service, while continually maintaining a safe environment for the public and for utility personnel. Operation involves the present and near future, while planning is concerned with the more distant future. The system operator must optimize the scheduling and control of a system after the decisions affecting the capital investment have been made. Thus he deals largely with the economics of energy delivery, under the constraint of maintaining safety and security.

Scope of research in planning and operation

One motive for conducting research in power system planning and operation is the prospect for substantial payoff. This leverage over future large capital and operating expenditures provides adequate incentive for a broad investigative effort. In making capital expenditure decisions, utilities must deal with future uncertainties. These include the reliability of lines and generators, the projected cost of fuel, the availability and cost of capital, the possibility of international fuel crises, and the regulatory climate.

Another important influence on system planning and design is the changing nature of the capital expenditure required. Table 1 shows annual capital expenditures for electric generation and transmission (G&T) for the past decade. The striking feature of these data is the rapid increase in generation expenditures compared with the modest growth in transmission investment. Whereas both costs were once of similar magnitude, generation costs now predominate, aver-

Table 1
CAPITAL EXPENDITURE
($ million)

Year	Generation	Transmission	Total
1966	2,535	1,438	3,973
1967	3,503	1,630	5,133
1968	4,280	1,917	6,197
1969	5,324	2,010	7,334
1970	6,860	2,123	8,983
1971	8,566	2,174	10,740
1972	9,737	2,148	11,885
1973	10,924	2,450	13,374
1974	12,504	2,450	14,954
1975 (est.)	11,845	2,564	14,409
Total	76,078	20,904	96,982
Percent	78.4	21.6	100

Source: *Electrical World,* September 15, 1975.

Table 2
CAPITAL EXPENDITURE FORECAST
(in 1975 $ million)

Year	*Generation*	*Transmission*	*Total*
1976	11,466	2,310	13,776
1977	11,515	2,260	13,775
1978	10,812	2,103	12,915
1979	10,502	2,067	12,569
1980	10,410	2,064	12,474
1981	10,515	2,101	12,616
1982	11,327	2,165	13,492
1983	13,591	2,539	16,130
1984	15,577	2,868	18,445
1985	16,377	3,043	19,420
Total	122,092	23,520	145,612
Percent	83.8	16.2	100

Source: *Electrical World*, September 15, 1975.

aging about 78% of the total G&T expenditure for the past decade. This is because of the rapidly escalating load growth during the period and the increasing capital unit cost of generating plants. Increasing unit cost ($/kW) is due largely to the trend toward nuclear plants, which are characterized by low fuel cost but high capital cost. Thus the future scheduling of nuclear plants is of critical importance and the premature installation of these costly facilities could have a severe effect on the financial condition of a utility.

The trend toward higher unit capital costs is forecast to continue for the decade ahead (Table 2). These figures reflect the deferral in plant construction schedules as a result of the load flattening of recent years.

Still, the overall effect is an increase in the proportion of system costs due to the growing unit cost of generation. This growth in unit cost data is verified if the year-by-year average plant investment is examined over the 20-year period 1966–1985. Using averages that include all investments in all plant construction, the trend is clearly up, with no present sign of leveling off. The net effect of these observations is that plant costs are projected as the dominant factor in the planning of future G&T systems. This fact is important in considering both the planning and the operation of future systems.

Power system planning Research in power system planning can be divided into the logical activity areas shown in Table 3. The area of system development is concerned with long-range forecasts of system requirements and with the means of meeting those objectives. This involves a consideration of the basic patterns of growth and change in the service area, as well as the projected economic conditions that affect growth.

Table 3
BULK POWER SYSTEM PLANNING RESEARCH

Area	*Objective*	*Strategy*
System development	Long-range planning	System expansion System forecasts Cost studies
	Short-range planning	Forecast tuning Peaking capability Network analysis
Planning strategies and tools	Strategic tools	Theoretical tools Reliability analysis Financial planning
	Simulation tools	Static simulation Dynamic simulation
Modeling, analysis, and evaluation	Analytic technology	Digital technology Hybrid technology System applications
	System modeling	Generation modeling Load modeling

Table 4
BULK POWER SYSTEM OPERATION RESEARCH

Area	*Objective*	*Strategy*
System control	Control strategy	Normal control Emergency control
	Control design	Control architecture Control components
System security	Security assessment	Computation needs Analytic needs
	Security assurance	Tactical selection Implementation
Communications, data, and measurements	Communications	Requirements Design Performance
	Data	Error control Management
	Measurements	Error control New technology

Much of the planning work is done by computer simulation. This necessitates the availability of a computer methodology and mathematical models of the system under study. The area of planning strategies and tools is concerned with the development of new and improved computer methods. These are divided into two categories: strategic tools and simulation tools. Strategic tools are basic mathematical and theoretical aids that can be used for deduction, estimation, and optimization of the uncertain processes in long-range planning. Simulation tools are the computer codes used by the engineer to find a class of feasible solutions. Simulation is an important component in planning as it provides a means to eliminate a large number of unworkable solutions, thereby considerably narrowing the field of choice.

Simulations are of little value, however, if the mathematical models are poor. Modeling, therefore, is an important part of planning and is shown in Table 3 as the area of modeling, analysis, and evaluation. Research in this area is aimed at providing an adequate computing technology and in developing accurate system models. These targets change continually as technology is developed in new areas.

Power system operation Power system operation is a complex activity. A portion of the system control is automatic and is under constant surveillance by control equipment. Much of the control, however, is under human supervision because of the decision making required to ensure safety and operational security. Exactly which functions are performed automatically and which by the human observer depend on the particular control center design.

One important goal of system operation is achieving the best economic dispatch of generation while maintaining adequate security. The human operator has the capability of intervening in the computer control program to schedule favorable purchases of low-cost energy on a few minutes' notice. This is one example of the man-machine interaction that has become commonplace in system control centers.

The logical areas of activity in system operation research are shown in Table 4. In system control, new control strategies based on performance objectives should be developed. New economic controls that account for present and future fuel and environmental constraints and for new load management methods also need to be developed.

System security assessment and assurance are highly theoretical areas that are in the early stages of development. These areas include both an improved off-line computer capability for operator use and an on-line estimation program that can perform routine surveillance checks.

The area of communications, data, and measurements is concerned with the quality and quantity of data transmission and with the management and processing of these data.

Research needs

A clearly defined need for research in system planning and operation exists in a number of areas, such as improved capability for dealing with the uncertainty of future events and minimizing the risk associated with erroneous predictions; improved understanding of system behavior and provision of more powerful tools of analysis for achieving this goal; and better methods of determining the costs of alternatives, including the cost of reliability and security.

The following are some of the specific areas in which research is needed.

System planning research needs In the short term the research anticipated in system planning is clustered around three target areas: improved simulation methods, improved reliability methods, and modeling. Simulation research is currently devoted to improvements in dynamic system performance. Projects are underway in long-term dynamics (RP907), mid-term dynamics (RP745), dynamic equivalents (RP904), and numerical methods (RP670). Work is soon to start on load modeling (RP849) and generator modeling. Research is planned on reliability methods. Other near-term needs are in boiler modeling and the cost of outages.

In the longer term we see the need for research on the impact of new technologies such as energy parks, new control concepts, and the effect of new system components (e.g., current limiting devices). We also need to improve the interface between the planning engineer and the computer by providing more selective output for a given purpose, study optimization techniques for power system application, and examine large-scale, perhaps regional, planning needs.

System operation research needs In system operation, the short-term goals are centered on control and security. New economic control techniques need to be developed that are pertinent to the operating conditions anticipated in the 1980s. On-line security assessment capabilities need to be expanded and implemented. Improved load-frequency control strategies need to be developed.

For the longer term, research is needed to provide continuous security surveillance and contingency evaluation. Regional hierarchical control that recognizes local constraints is a long-term goal.

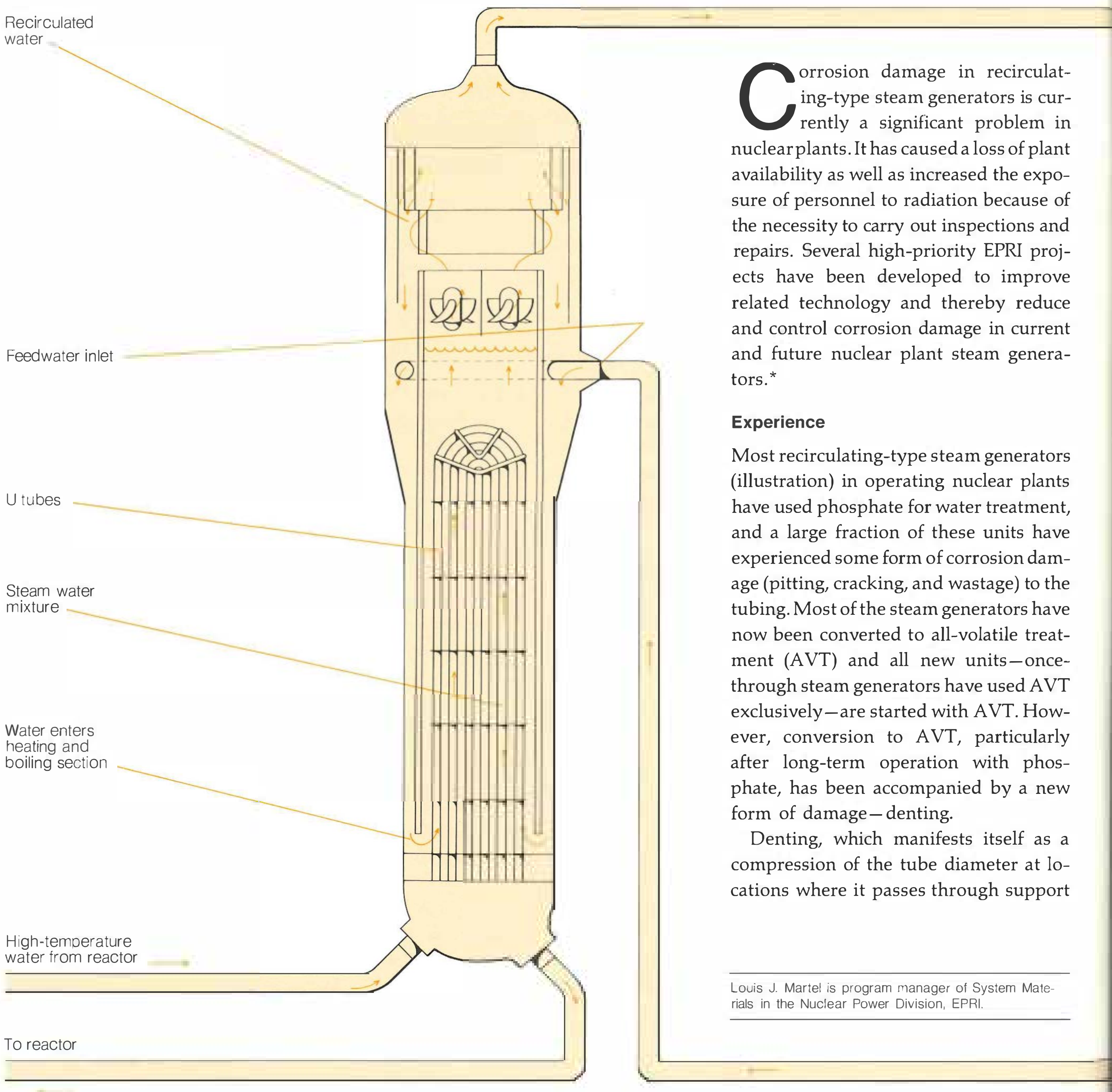
Capital for the future

The electric power system is presently the world's most capital-intensive industry and is becoming more and more so. This trend places a burden on utilities to attract capital for needed construction. It also places a great responsibility on the power system planners and operators to accurately determine future needs and to efficiently operate these facilities. The techniques used in these studies are largely analytic and attempt to deal effectively with the uncertainty of future events. The leverage over future large expenditures is great and the possible payoff is high. Thus, even small improvements in the analytic methods can yield substantial benefits. It is anticipated that research will be continued on these important methodologies as long as benefits can be realized.

Corrosion Damage in Nuclear Steam Generators

by Louis J. Martel

Corrosion damage in steam generators is a principal contributor to lowered plant availability. The complex mechanisms that cause corrosion are just beginning to be understood. EPRI is carrying out a broad program to advance technologies that will eliminate the high impact of corrosion damage. ▫ An EPRI technical feature



Corrosion damage in recirculating-type steam generators is currently a significant problem in nuclear plants. It has caused a loss of plant availability as well as increased the exposure of personnel to radiation because of the necessity to carry out inspections and repairs. Several high-priority EPRI projects have been developed to improve related technology and thereby reduce and control corrosion damage in current and future nuclear plant steam generators.*

Experience

Most recirculating-type steam generators (illustration) in operating nuclear plants have used phosphate for water treatment, and a large fraction of these units have experienced some form of corrosion damage (pitting, cracking, and wastage) to the tubing. Most of the steam generators have now been converted to all-volatile treatment (AVT) and all new units—once-through steam generators have used AVT exclusively—are started with AVT. However, conversion to AVT, particularly after long-term operation with phosphate, has been accompanied by a new form of damage—denting.

Denting, which manifests itself as a compression of the tube diameter at locations where it passes through support

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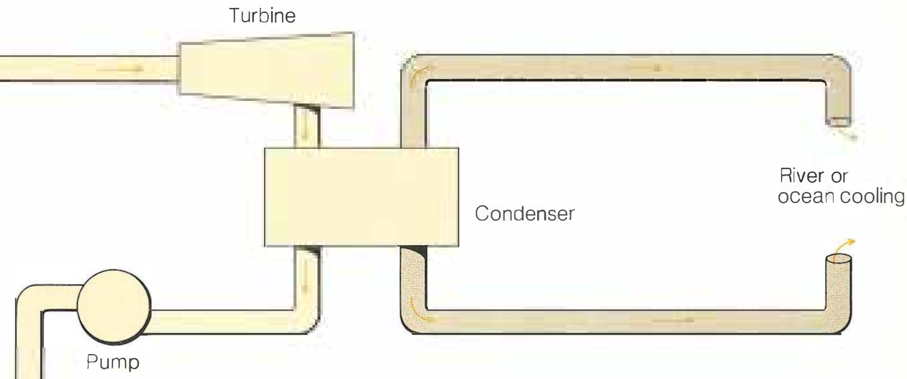
plates, is believed to be caused by the accelerated corrosion product buildup in tube-to-support-plate crevices. Steam generators that have been operated solely with AVT (this has been for a relatively short time) are reported to be generally free from corrosion damage.

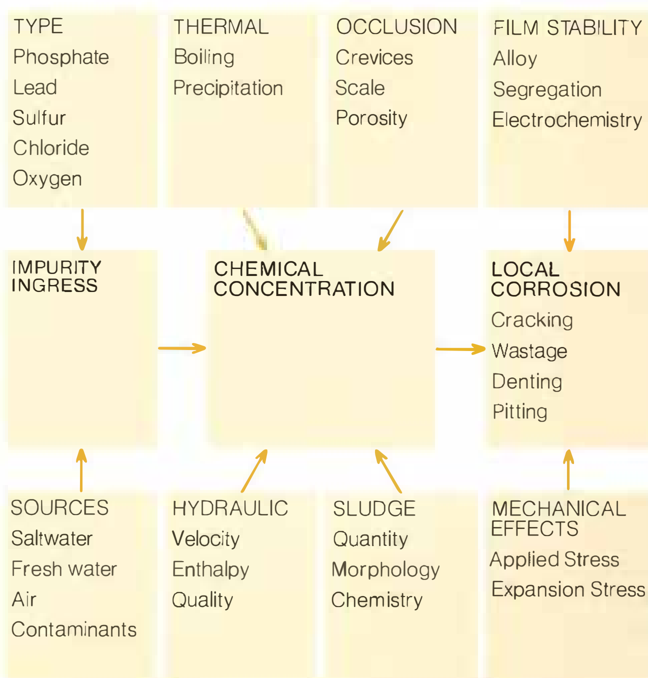
Nuclear versus fossil steam generators

Some factors in large commercial nuclear steam generators make them more prone to secondary side corrosion damage than would be the case for fossil units.

- The large open fluid volume on the secondary side makes flow distribution difficult to predict because of the thermal and hydraulic impedance assymmetries that exist.
- Sludge accumulations alter the fluid flow during the life of the unit.
- Sludge accumulations are located in areas of maximum heat transfer.
- Numerous crevices exist at locations of maximum heat transfer.
- Alloy 600 tubing, which has excellent general corrosion resistance, can be susceptible to local corrosion in certain environments where there is a concentration of feedwater impurities.
- Small amounts of radioactivity in the boiler water can inhibit the use of high blowdown rates that could otherwise be used to counteract the effects of inleakage of impurities.



In the control of secondary system corrosion, there are three problem areas: inleakage of air and of cooling water in the condenser, chemical concentration in the steam generator, and local corrosion attack on U tubing and support structures. The interrelationship of these three are plotted below.



These various factors suggest that the eventual solution of corrosion damage problems in nuclear steam generators will probably require a combination of improvements in design and operation of steam generators, condensers, and feedwater cleanup systems, as well as improvement in integral design, operation, and control of the secondary system.

The corrosion damage process

Essentially, there are three steps in the corrosion damage process that occurs in steam generators during operation:

- The ingress of impurities into the secondary system
- The average and local concentration of impurities in the steam generator
- Local corrosion attack on steam generator materials by highly concentrated impurities

Impurity ingress Impurities entering steam generators can be traced to condenser cooling water inleakage; air inleakage; makeup water; demineralizer resin and regeneration chemicals; various soluble and insoluble corrosion and erosion products; some water treatment chemicals, such as phosphates; other contaminants, such as air, oil, preservatives, and packing that sometimes enter systems when they are under construction or are opened up for inspection and repair.

Significant quantities of chemicals are introduced into steam generators, even though the concentration of entering impurities is generally in the part-per-billion concentration range. Large steam generators in nuclear plants collectively produce up to 13 million pounds of steam per hour, which is equivalent to complete boildown of the entire secondary side volume about once each minute. At these throughput rates, 10 ppb of impurities in feedwater—which is equivalent to a saltwater leakage rate of 0.005 gpm—amount to an input of about 1000 lb/yr. In practice, annual accumulations of these magnitudes are not realized because soluble impurities are removed largely by blowdown, and to a lesser extent by carryover. The insolubles, which are mostly iron and copper oxides, are only partially removed by blowdown, and consequently, most of these accumulate as sludge in the steam generator. However, certain chemical species such as chlorides, which would be expected to be soluble in boiler water, are somehow retained as insolubles in steam generator sludge.

The type and quantity of impurities that are within a steam generator at any given time and their availability for concentration near material surfaces are important considerations in assessing impurity ingress.

Chemical concentration The dominant driving force for chemical concentration in steam generators is the boiling or evaporation process. The boiling process produces relatively pure steam and a chemical residue in the remaining liquid phase. This concentrating tendency is counteracted by good hydraulic conditions, which tend to redilute the local boildown areas and restore them to the bulk chemistry. However, the large open fluid volume on the secondary side makes it very difficult to ensure that the local fluid flow conditions do in fact provide adequate wetting of heat transfer surfaces on a local scale approximating the size of a single tube.

Sludge and occluding conditions, such as scale and crevices, are additional important and complex factors that can promote local impurity concentration. About one half the volume of sludge on steam generator tubes consists of open porosity. Large quantities of boiler water flow through these pores and absorb heat to produce steam. Chemical concentration will tend to take place in these small pores and be incorporated within the sludge.

The interaction between the sludge and the impurities can result in permanent or temporary incorporation of these impurities or can involve direct chemical reactions to produce new species that can then corrode tubing materials.

These circumstances and the rather incomplete knowledge of the solubility and chemical form of many of the species that exist at high temperature and pressure, as well as the practical problems in making direct measurements in operating steam generators, make it difficult to predict corrosion damage.

Local corrosion Local corrosion—not general corrosion—is the most common type of damage in steam generators. The forms of local corrosion that have been observed are pitting, wastage, and intergranular stress corrosion cracking. When local corrosion occurs, it tends to be in certain zones of the steam generator:

- Tubesheet crevices
- Areas just above the tubesheet and possibly just underneath the top of the tubesheet sludge piles
- At and near support plate crevices
- At the upper U-bend regions, particularly at tube support devices

Chemical concentration factors can be associated with all these zones. This observed correlation, in conjunction with an absence of a material-related correlation, is the basis for the belief that chemical concentration, and not materials, is the probable cause of tubing corrosion damage. The factors related to denting are not clear at the present time, but concentration of some form of chemical is probably one of the factors involved.

The oxide-film stability on Alloy 600 tubing is the factor that governs its behavior in the presence of concentrated chemicals. The film stability—in combination with the electrochemical potential of the environment—controls the local corrosion behavior of the tubing alloy.

Local corrosion occurs when electrochemical conditions are in transition states for the ionic species of the dissolved film. The rate and detailed form of corrosion damage occurring when the chemical environment is at these transition regions are also affected by many factors: stress, crystallographic slip behavior, alloy segregation (particularly at grain boundaries), and other detailed considerations that control anode and cathode electrochemical behavior. In order to avoid these complexities in material behavior, it is necessary to control the chemical environment to ensure the existence of stable, protective oxide films. This is a difficult but necessary task in the design and operation of steam generators and secondary systems if corrosion damage problems are to be eliminated.

EPRI research

The goal of EPRI projects on steam generators is to advance and apply technologies that will ensure that corrosion damage is no longer a high-impact problem. The projects are directed toward all three of the steps involved in the corrosion damage process: dilute chemical ingress, chemical concentration, and local corrosion. Current and planned efforts are listed below. Most of the laboratory, plant, and engineering studies are covered in existing programs or will be funded in the near future.

Laboratory studies High-temperature corrosion; high-temperature thermodynamics; steam solubility; Pourbaix diagrams; and colloidal chemistry.

Plant and engineering studies Secondary chemistry and corrosion damage in operating plants; secondary chemistry and corrosion damage in new plants; performance of existing condensers; leakage performance of titanium tube condensers; model boiler studies; chemical cleaning to avoid corrosion damage; and AVT plant performance.

System studies Components; system design; and operating and chemistry controls.

The following projects are now underway to determine the cause of and to prevent corrosion damage to steam generator tubes:

Corrosion research at Ohio State University The focus of this project is to study and rationalize corrosion processes in material-environment combinations that are of interest to electric utilities. This broad effort emphasizes basic corrosion technology. Specific tasks are to (1) develop an overall understanding of the corrosion mechanisms and electromechanical behavior of Alloy 600, (2) identify boiler water chemical species that attack Alloy 600, and (3) evaluate condenser tube stress corrosion and cracking behavior in ammoniated environments.

Thermodynamic studies of ionic species at San Diego State University This project is to describe the high-temperature and -pressure thermodynamic properties of ionic species expected to be in boiler water. Data from this program will greatly increase the meager information now available on this subject.

PWR secondary water chemistry study by Nuclear Water and Waste Technology, Inc. (NWWT) The purpose of this project is to characterize the secondary system water chemistry of five nuclear plants and to relate this chemistry to steam generator tube damage. Of particular interest are those chemical species that may cause tube damage during plant operation when there is cooling water or air inleakage.

Model boiler project at Combustion Engineering, Inc. This research is to define those chemistry conditions that cause, and those that avoid, tube damage under conservative conditions simulating those of recirculating steam generators now operating with AVT. One objective is to duplicate and rationalize corrosion damage in operating plants. Data from this project will be used to help define secondary chemistry operating conditions, as well as to improve secondary system technology.

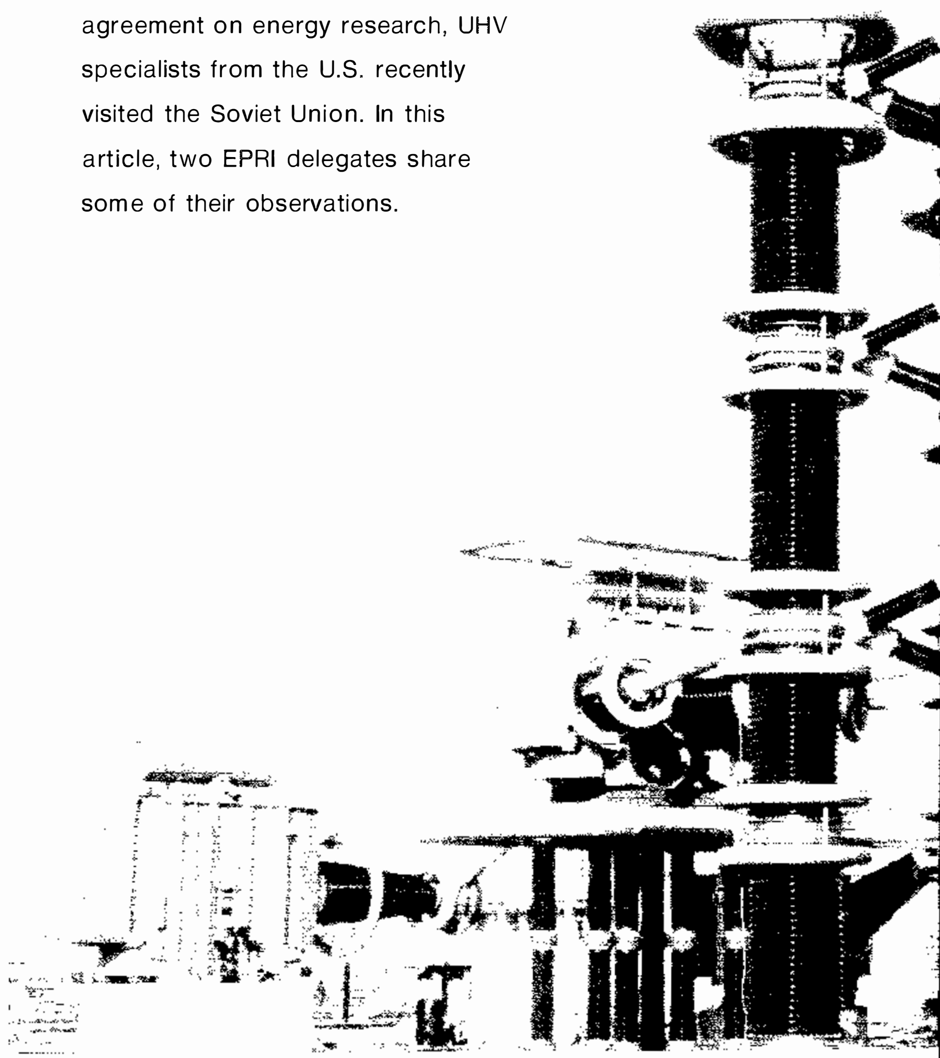
Evaluation of condenser performance at Bechtel Corp. The objective of this project is to appraise condenser cooling water inleakage in large (>300 Mw) electric utility power plants. A field survey is to to be made of 30 stations, about half of which are nuclear, with emphasis on the performance of condensers with titanium tubes.

*L. J. Martel and W. L. Pearl. "The EPRI–ASME Program to Study PWR Water Chemistry." In *Proceedings of American Power Conference* 37:765–771, 1975.

UHV Transmission Research in the USSR

by Frank S. Young and
Ralph S. Gens

As part of a U.S.–USSR exchange agreement on energy research, UHV specialists from the U.S. recently visited the Soviet Union. In this article, two EPRI delegates share some of their observations.



The USSR is investing millions of dollars and employing some of its best talent on UHV transmission research. Efforts involve not only 1200-kv ac line work but also ± 750-kv dc transmission. These are among the facts we learned during an April visit to the Soviet Union as part of the U.S.–USSR technical exchange on UHV transmission technology.

EPRI technical staff and advisory committee members have a significant role in this exchange. In addition to the authors, our 1976 delegation included Narain Hingorani, EPRI program manager for AC and DC Substations; William R. Johnson of Pacific Gas and Electric Co., T&D Division Committee chairman; Jake Sabath of Southern California Edison Co., DC Task Force chairman; and Frank Fischer, Consolidated Edison's project manager for the EPRI-sponsored DC Prototype Link (RP213). Other industry participants were Dave Melvold of the Los Angeles Department of Water and Power, Frank Denbrock of Commonwealth Associates, and Fred Ellert of General Electric Co. Val Lava of BPA was our interpreter.

Three joint meetings on UHV transmission have been held to date. Some of the objectives have been accomplished; the means for accomplishing others are beginning to appear. Patience is required in international technical work because of differences not only in language but also in academic background and engineering economics.

The first meeting (1974) was held in Moscow to negotiate the method of exchanging technical data and to establish areas for joint research. Two symposiums were organized, one to deal with ac transmission technology and the other, with dc transmission. Joint ac transmission research was planned on overvoltage protection of UHV systems, reactive

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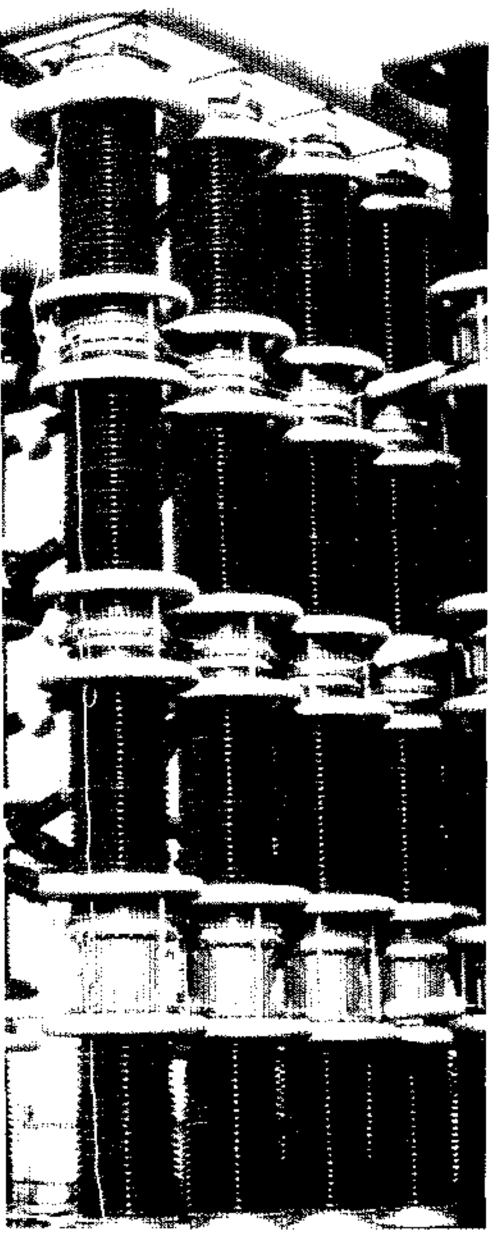
The first of two dc test sets at the Leningrad high-voltage laboratory. It can produce either plus or minus 1200-kv dc, with a 400-kv (peak), 50-Hz ac voltage superimposed.



power control, line insulation, design of UHV structures, and reliability.

The 1975 meeting was an ac symposium in Washington, D.C. Papers on system design, conductor selection, electric field effects, structure design, and conductor vibration were prepared and presented by Soviet and American authors. While many practices were found to be common to both countries, others were recognized as being quite different. Most notable among the latter are the assessment of electric fields, the use of V-string insulators, the methods of dielectric testing for switching surges, and the means of controlling transient overvoltages on the systems.

The third meeting, a dc symposium held April 7–10, 1976, in Leningrad, featured papers presenting a general overview of dc transmission, overvoltages on dc lines, line insulation, conductor selection, harmonics, and operating experience on both the U.S. Pacific Coast DC Intertie and the Soviet Volgagrad-Donbas DC Line.

Soviet research priorities

Leningrad is the center for dc research in the Soviet Union, but a substantial amount of ac insulation research is conducted there also. During our 1974 visit we saw scale models and heard detailed reports on new high-voltage laboratory facilities that were to be built as part of the next five-year plan.

On our return this year, two things became apparent regarding UHV research efforts. First, the Soviet government is investing a large sum of money in HV laboratory facilities for both ac and dc transmission research. The laboratory complex in Leningrad, only a model in 1974, is under construction. The cost quoted by the laboratory manager was 10 million rubles, which is roughly equivalent to $13.5 million at current exchange rates.

Our second discovery was that Soviet engineers have modified their testing procedures. For example, in line insulation research Soviet engineers historically performed switching surge tests with conventional cascade test transformers excited from a small capacitive discharge circuit. The resultant wave shapes had extremely long fronts in the 4000–5000-μs range. On the other hand, engineers in the U.S. (as well as in Europe and Japan) historically used an impulse generator employing a Marx circuit to produce test voltages for line insulation studies. These voltages are double exponential, with wave fronts in the 50–1000-μs range. At the 1975 symposium, Soviet and U.S. engineers vigorously defended their respective test methods, the Soviets claiming that theirs more closely approximated actual surges appearing on UHV systems.

New laboratory facilities

In April of this year, however, the Soviets were installing a first-class impulse generator in the new Leningrad facility. The new generator is described as a 5000-kv unit that can be expanded to 7500 kv. It will produce wave fronts from 1 to 5000 μs, giving Soviet engineers a capability for UHV research they have not previously had.

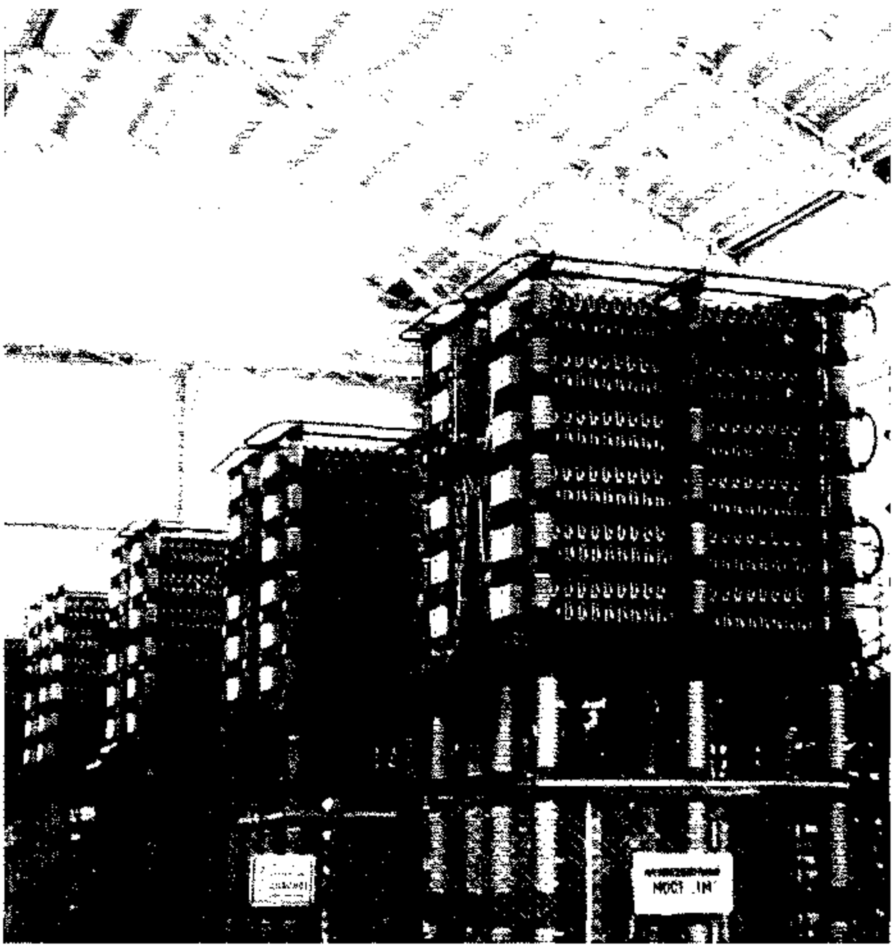
A cascade transformer rated 1800 kv, 50 Hz rms, and 2 amp continuous current capacity has been installed at the laboratory complex.

A unique new piece of test equipment is a dc set rated for either plus or minus 1200 kv dc, with the capability of superimposing a 400-kv (peak), 50-Hz ac voltage on the dc. A second set will eventually be installed to enable ±1200-kv dc research. This set is designed for a continuous current rating of 0.5 amp.

In one of the papers presented this year, the Soviet authors identified the types of overvoltage at which they expect to stress line insulation. One overvoltage appears as a dc component with a power frequency "ripple" component. The new ±1200-kv dc test set will be used to investigate insulation requirements for this type of wave shape.

The Leningrad laboratory has a sizable building for indoor testing. At the outdoor laboratory, a large mobile crane is available to move test tower structures.

Solid state thyristor valves are tested in a back-to-back rectifier and inverter circuit at Moscow's Bely Rast Substation research facility. This system is rated for 375-Mw power transfer at 2000 amp and 187.5 kv. Each valve contains 216 water-cooled and air-insulated thyristors 30 mm in diameter. Beams of light (through air) go from the control room to each valve group, where they are converted to electrical pulses that fire the thyristors.



It was especially interesting to us that the new laboratory complex is in the middle of a new residential area. Apartment buildings border the lab area, which is about the size of a large city block. When we asked why the lab is not in the country where more space would be available for expansion, the answer was given that it would be too hard for the lab technicians to get to work. Apparently, apartment residents have considerable tolerance for the noise from flashovers, because the Soviet engineers said they don't expect any objection on this point.

One often gets the impression that the pace of Soviet construction is slower than in this country; yet before the end of 1976 a new high-voltage lab, capable of performing significant research on both ac and dc insulation systems, will be in operation in Leningrad. It represents a major increase in the Soviet UHV research capability.

During the 1974 exchange meetings, we also visited transmission research facilities near Moscow. The Moscow site is the Bely Rast substation. An 1150-kv ac test line about half a mile long and a 750-kv dc test line of about the same length are in service there. Also at this substation is a dc valve testing facility, using a back-to-back circuit. Although the facility has not been completed, converter equipment with solid state valves has been installed. Testing of this equipment was demonstrated during our 1976 visit, even though full load was not possible at that time.

Exchange objectives

The exchange program on transmission research is part of a broader program on energy. Other programs are also in progress, such as those in the fields of medicine, agriculture, and space. The most spectacular joint project so far was the 1975 Apollo-Soyuz space flight. Though not so glamorous, the UHV transmission exchange is also aimed toward high goals. Its principal objective is to share meaningful and useful technical design data and operating experience on both ac and dc transmission lines operating at EHV and UHV. Joint research projects have been organized. The work will be carried out in both countries, and experts will be exchanged.

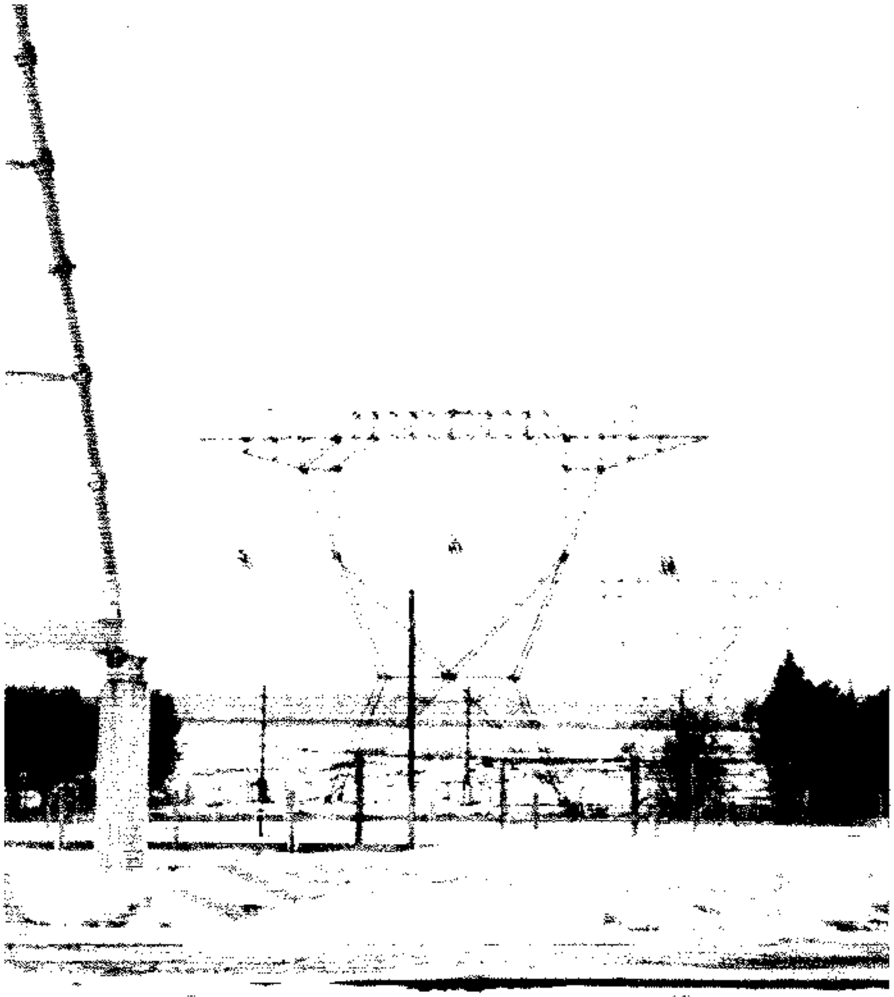
Contrasting national objectives

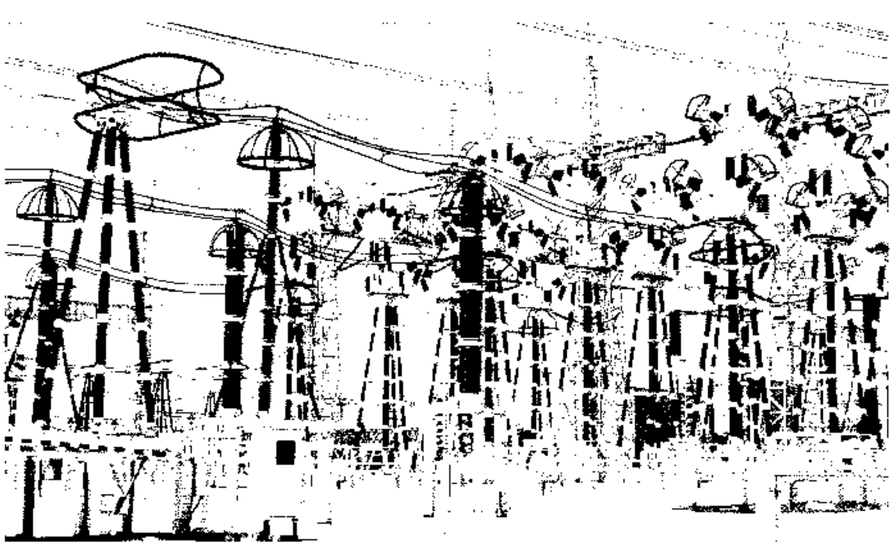
Long-distance UHV ac or dc transmission must be kept in the proper perspective when comparing Soviet motives and needs with U.S. requirements. The geoeconomic situation in the USSR is not the same as in the U.S. A large proportion of Soviet natural resources (hydroelectric power sites, for example) are in the eastern (Siberian) area of the country, while most of the population is in the western (European) area. Long UHV circuits, therefore, appear economically viable.

The distribution of coal reserves in the two countries is similar, however, and both countries are investigating UHV as a means of facilitating the use of these resources.

Of specific interest were Soviet plans discussed in 1974 for their UHV ac and dc line construction. They have designed a 2400-km dc transmission line to operate at ±750 kv. Terminals will be at Ekibastuz and Center. Power transfer capability will be 6000 Mw. The converter terminals will use the latest Soviet solid state technology. In 1974 the impression was given that construction of this line and its associate terminals had been approved; but in 1976 we discovered that no definite in-service date had been established because the line had been dropped from the current five-year plan. However, we learned that the plan does include a back-to-back dc tie with Finland that will use

Two-year-old 1150-kv experimental line at Moscow's Bely Rast Substation features I-strings of insulators. More recent Soviet designs employ a V-string for the center phase (reducing tower window width), delta conductor configurations, and guyed towers—any of which tends to cut structural cost as well as right-of-way width.





765-kv switchgear at Moscow's Bely Rast Substation typifies Soviet commercial practice today. Air-blast circuit breakers are at the right; a disconnect switch is at the left.

converter equipment similar to the Ekibastuz-Center terminals.

UHV ac lines will be used in the USSR as an overlay for 500-kv systems. Tower drawings displayed in 1976 show an interesting departure from previous Soviet practice—the use of V-string insulators in the tower window and of a delta conductor configuration. Soviet engineers also told us that they are now using five-conductor bundles on 765-kv lines.

Future expectations

A number of advances can be expected from joint Soviet and U.S. research in the near future. In dc transmission, two subjects for investigation have been identified. One deals with fault transients on overhead lines. There are two aspects: overvoltages that appear on the line as a result of converter faults and, conversely, overvoltages that appear in the converter station as a result of dc line faults.

The second dc research project concerns harmonics that appear on the ac system. Studies will be made of HV dc transmission system operation and its interaction with the ac system from the harmonics viewpoint.

The determination of Soviet power engineers is reflected in their dedication to the solving of UHV ac and dc transmission problems. This is evident from our face-to-face technical exchanges and visits to research facilities, during which we share problems, successes, and insights that have not been routinely reported in the international literature.

Further exchange of technical papers is also under study, one subject of major interest being the interaction of dc transmission with interconnected power systems as a means to enhance the reliability of entire networks. Meantime, papers prepared for both the ac and the dc symposiums, along with summaries of the 1975 and 1976 technical discussions, have been published and are available from the Bonneville Power Administration. These volumes contain both Soviet and U.S. contributions and are valuable references that summarize the state of the art in ac and dc UHV transmission technology in both countries.

Arthur Stern Clears the Air

This interview with Chairman Arthur C. Stern is the first in a series of JOURNAL interviews with EPRI Advisory Council members.

The Advisory Council, a panel of prominent leaders in government, labor, education, science, and business, provides a link between the public served by the utilities and EPRI's Board of Directors, officers, and staff. At its quarterly meetings the Council reflects the attitudes and needs of the public and, in that light, makes recommendations on EPRI program direction.

Arthur Stern's 6-foot-4 stature matches his prominence as an authority on air quality. His expertise is tapped regularly by government and industry and his views are sought frequently at air pollution conferences in the United States and abroad.

That expertise comes from more than 40 years of experience, dating back to the mid-1930s when he directed air pollution surveys for the health department of New York City. In 1955 Stern went to Cincinnati to set up the first federal air quality program for the U.S. Public Health Service, pioneering federal research, training, and technical assistance programs to combat air pollution. That groundwork led to formulation of the landmark Clean Air Act, which became law in 1963. Stern joined the academic community in 1968, and has since held a professorship in air hygiene at the University of North Carolina.

Stern has approached his role as chairman of EPRI's Advisory Council from a broader perspective than his recognized expertise and academic credentials would in themselves justify. "All through my professional career, starting in 1930," says Stern, "I've had continual contact with committees and councils—fre-

"I see my role as expediting the work of the Council to accomplish the ends we set up."

quently as their chairman—and have developed a certain know-how in making them work, making them move. I see my role as expediting the work of the Council to accomplish the ends we set up."

Members of the Council, Stern feels, likewise "tend to view their roles as not being spokesmen for a particular constituency, but rather in giving EPRI the best advice they can." He sees the Council membership as having "sufficient balance among various segments of the community" so that it truly reflects the interests of those who would be affected by whatever direction the electric power industry may take.

Stern is gratified that the two-year-old Advisory Council has reached the point where it is "ready to take over a larger share of its own direction and agenda." Council meetings now consist more of discussion by council members of issues and reports they generate themselves than of listening to presentations by EPRI staff, as in earlier meetings.

And the recent creation of four Council committees to work on specific areas of concern "is a step in the right direction," as Stern sees it. The committees—on national issues affecting EPRI, environment and ecology, communications, and power sources and uses—are showing "considerable progress and momentum that should give us more substantive output in the future," he adds.

Stern comments that "the mere volume of EPRI research reports is certainly awesome—you can fill a couple of file drawers in a short time—and indicates that something is happening."

Granted the volume is heavy, what does he think of the research being done under EPRI sponsorship in his speciality of air quality? "Those reports that I have seen have been done by contractors of good repute," he observes, adding that this indicates EPRI carefully selects its contractors who, in turn, do a careful job. The result has been "a uniformly good series of documents in my field."

The environmentalists on the Council, himself included, have felt that EPRI's early research projects dealt mostly with engineering and scientific matters having to do with burning fossil fuels or with the operation of nuclear reactors, and the like. They let it be known that they would like to see more environmental emphasis and, in fact, "the budget has changed in this direction," Stern notes. The expression of this viewpoint by a segment of the Council, Stern believes, has contributed to the environmental balance in EPRI's research program.

Stern is concerned about governmental regulations under the Clean Air Act that control power plant emissions. He has said that the American public has been forced to spend billions of dollars to provide more control on the automobile than is necessary. Does he see the utility industry in a similar cost bind in having to meet federal standards for plant emissions?

Stern believes that "present EPA policies and the direction Congress is taking in amendments to the Clean Air Act could very well cause the same situation to occur, where the expenditures would far exceed the benefits to the public." He cited the following particulars.

"We are trying to meet air quality standards based on data that have not been updated since 1968." And it is "discouraging," he says, that the efforts at updating and revising the data by the National Air Quality Advisory Committee of the EPA, which he chairs, will come to an end June 30 when the committee is phased out. "There is a certain amount of discouragement," Stern reports, "that the work may well be getting started but will not come to a conclusion, and we will

"We are trying to meet air quality standards based on data that have not been updated since 1968."

"The only way we'll get people to conserve our resources is to make the constraints mandatory."

"We are going to run out of fossil fuels and uranium . . . conservation merely will delay the date."

still be left with air quality criteria documents seven or eight years out of date. This means that plants now on the drawing boards, which will come on line five years from now, will be regulated by standards based on data developed ten to fifteen years earlier and never revised."

The result could be air quality standards more stringent than necessary. In Stern's opinion, "A new look might very well show that the standards are perhaps more stringent than they need be and there could be some relaxation without adverse effects on health." He cites EPA's hydrocarbon standard, for example, as "being on very weak ground and yet there is a rather sustained drive, a single-minded effort [by EPA] to achieve that standard.

"Another related difficulty facing the industry," Stern points out, "is the stand taken by the EPA, and apparently by Congress as well, which says that supplementary control systems will not be acceptable for steam power plants." Stern explains that these systems take advantage of the ability of the atmosphere to cleanse itself.

"This self-cleansing process has been going on ever since the earth was formed," he says, "and the position of EPA and Congress that we cannot use the assimilative capacity of the atmosphere seems to me to fly in the face of reality. The result is to deny the public the right to a less expensive method for getting rid of air pollution in favor of the costly continuous control systems, such as gas scrubbers. This is where some of the billions of dollars in cost difference occur."

Recommendations were made to Congress last year by the Air Pollution Control Association (APCA), of which Stern is president, on revisions of the 1970 Clean Air Act, but Congress thus far has ignored those recommendations, Stern regrets to say.

In speeches around the country as president of APCA, Stern has been calling for conservation of energy, urging that we must stop "frittering away our resources." But he recognizes that conservation means different things to different people. A person who loves the wilderness may think it wasteful to drive to a football game, while a sports fan may consider it frivolous to travel 100 miles to watch birds in the wilderness, Stern suggests.

Stern says he was one of those who favored gas rationing to help meet the 1973–74 Middle East oil embargo, and that "the only way we'll get people to conserve our resources is to make the constraints mandatory. I go about doing many things I shouldn't if I wanted to conserve energy," Stern admits, "like driving in a car alone. If there were universal rationing that said, 'This is all the gasoline, all the electricity, all the oil you're going to get, use it the way you think best,' then I would be willing, of course, to live under this kind of regime. I can't see that my own contribution, if not paralleled by that of every other citizen, is going to be meaningful."

However, Stern believes that whether or not we conserve, "we are going to run out of fossil fuels and uranium at some future generation, and conservation merely will delay the date." He asks, "Is it significant to those alive today whether the catastrophe [depletion of fuels] occurs at the 37th or the 44th generation from now?

"Since we are going to continue to exist as a society," Stern says, optimistically, "we are going to have to develop solar and wind, tidal and vegetative sources of energy."

As Arthur Stern has been saying in his APCA talks, "It's with a sense of *déjà vu* that I perceive what the future holds in the energy-industry-environment-society complex. As we begin again to learn to live with less oil and natural gas, I see us time and again rediscovering the wheel as we increasingly disengage ourselves from the use of these fuels. Perhaps we shall rediscover the gas works, smokeless coal, domestic stoker, the trolley car, interurban trains, district heating, and the electric automobile that we thought we had put behind us 50 years ago."

Arthur C. Stern has devoted four decades of his professional career to policing the air we breathe. In honoring him this year with election to the prestigious National Academy of Engineering, the NAE cited Stern for "pioneering technological development for assessing air pollution, nationally and internationally." A year earlier his alma mater, Stevens Institute of Technology in Hoboken, New Jersey, bestowed on him an honorary doctorate of engineering. He had earned MS and ME degrees at Stevens in the early 1930s. After Stevens, he was director of air pollution surveys for the New York City Department of Health and then engineering chief of the Division of Industrial Hygiene and Safety Standards for the New York State Department of Labor.

Stern left New York for Cincinnati in 1955 where he set up the research, training, and technical assistance program of the U.S. Public Health Service. After some six years in Cincinnati and seven years in Washington as assistant director of the National Air Pollution Control Administration, he took up a professorship in air hygiene in the Department of Environmental Sciences and Engineering at the Chapel Hill campus of the University of North Carolina, where he has been since 1968. Stern is an adviser to many committees and councils and serves as chairman of the National Air Quality Criteria Advisory Committee of the U.S. Environmental Protection Agency.

He is editor of the five-volume reference, *Air Pollution* (3d ed., 1976), coauthor of *Fundamentals of Air Pollution* (1973), and has been published in numerous technical journals. Stern is a Life Fellow of the American Society of Mechanical Engineers, a Diplomate of the American Academy of Environmental Engineers and the American Board of Industrial Hygiene, and a recipient of the Air Pollution Control Association's Richard Beatty Mellon Award, among other honors. In 1975 he was elected president of the APCA.

In July the chairmanship of the Advisory Council passes from Arthur Stern to Vice Chairman Ruth M. Davis, director of the Institute of Computer Sciences and Technology at the National Bureau of Standards, who will be the subject of our next interview.

R&D Status Report
ENERGY SYSTEMS, ENVIRONMENT, AND CONSERVATION DIVISION

René Malès, Director

ENVIRONMENTAL ASSESSMENT DEPARTMENT

Data Bases

The objective of this subprogram in the Environmental Assessment Department is to collect and organize the information and data needed to support the department's research and to help the utility industry to develop improved environmental impact assessments. To accomplish this task, EPRI is familiarizing itself with, and drawing on, existing data bases. In particular, the data bases under development by the Environmental Protection Agency, the Brookhaven National Laboratory, the Federal Energy Agency's National Energy Information Center, and the Atomic Industrial Forum will be used. In addition, EPRI has direct access through computer terminals to the information systems developed by Data Resources, Inc., by the Lockheed Retrieval Service Information Systems Laboratory (DIALOG), and by Oak Ridge National Laboratory (RECON).

Access to these information and data systems allows EPRI to investigate areas associated with environmental questions in an effort to define research needs and priorities. In areas where existing systems are deficient or require interpretation, EPRI is developing its own data bases. Three research projects are involved in such development.

Under RP381, a review of the literature and of the ongoing research on biological effects of high-voltage electric fields has been completed and a report has been published. A second research project (RP571-1) will result in a series of topical reports reviewing the health effects of selected fossil fuel pollutants, based on available toxicological and clinical research data. Reports already published cover selenium and NO_x.

In addition, EPRI and members of the nonferrous smelting industry are sponsoring an ongoing two-phase air pollutant health effects project with Arthur D. Little, Inc. (ADL), Cambridge, Mass. (RP331). The first phase of the project is devoted to the preparation and maintenance of a scientific data bank that includes extensive information on the effects reported in human beings, animals, and plants by exposure to SO_x, Pb, Cd, As, O_3, and NO_x. The data bank is constantly updated to include the latest information available from both domestic and foreign sources. This is accomplished by continuously surveying the published literature, by sending trained staff members to scientific meetings, by interviewing scientists conducting research in areas of interest, and by recording the findings reported.

The data bank is used by ADL staff trained and experienced in data interpretation and in responding to questions posed by the sponsoring organizations. In the $3\frac{1}{2}$ years since its initiation, the data bank has proved to be an effective source of information for use in critiquing scientific publications, preparing the scientific background for legal briefs, and in designing, conducting, and evaluating environmental, hygienic, and toxicological studies of laboratory animals and human beings in both industrial and urban surroundings.

EPRI members can access the information by first sending questions to Stephen B. Baruch of Edison Electric Institute (EEI). After reviewing the data requirements with EPRI staff, EEI forwards the question to ADL for response.

To date, requests to this program have included an overview of problems associated with the evaluation of air pollution health effects, information on the effects of sulfur oxides and sulfate concentrations on the growth of alfalfa, evidence of reduced growth or weight gain in cattle as a result of sulfur oxide emissions, information on the effect of sulfur oxides on pecans, and a critical review of draft EPA reports that describe the recent CHESS (Community Health Environmental Surveillance Systems) findings.

As further needs become evident, new data bases will be established. A project is planned to compile annotated bibliographies of literature and data sets relevant to the assessment of the impact of thermal power plant cooling systems on aquatic environments. EPRI also plans to compile a data set of cooling system and cooling water characteristics for large thermal power plants. *Project Managers: Harry Kornberg, Ron Wyzga*

ENERGY SUPPLY STUDIES PROGRAM

Data and Methodology Development

This subprogram provides analytic tools to support the Energy Supply Studies Program and other division efforts. Its primary objective is to develop data and methodologies for use in energy supply analysis. Projects are directed toward incorporating uncertainty measures into energy forecasting, integrating physical and behavioral sciences and economic and engineering techniques in the study of energy supply, applying measures of reliability to data collection, and developing and analyzing data bases. By incorporating realistic measures of uncertainty into energy supply analysis, the subprogram hopes to bring about major advances in forecasting techniques and in the usefulness of forecasts.

Several projects are currently underway. One study, RP628, seeks to develop measures of uncertainty in the data results of input-output (I–O) analysis by examining the effect of error. I–O tables provide economic information on intermediate activities of the industrial sectors of the economy; they are developed periodically by the Bureau of Economic Analysis (BEA). Uncertainty in the tables can be the result of error in the base year estimates from which the table is derived or can be due to technological change during the period from the base year to the year of interest. Normally, however, results of I–O analysis are presented without any measure of uncertainty.

The contractor for this project is the Center for Advanced Computation at the University of Illinois. In a previous study for AEC, the center developed analytic bounds for some of the parameters involved in I–O analysis. However, the analytic results do not provide sufficient information on the magnitude of uncertainty that might arise. In an attempt to improve this situation, the researchers will perform a Monte Carlo simulation of an I–O table, employing estimates of the variances of the raw data used by BEA to construct its I–O table. Following the BEA procedure for constructing a table, the researchers have stochastically chosen an entire transaction matrix and vector of final demands. The outputs are computed, and the process is repeated to obtain the means and variances of the outputs. The results are probability distributions of the output, based on distributions of the input data.

The project will provide the first realistic examination of uncertainty in a large-scale I–O table. For the purpose of this project, 30- and 100-sector tables were examined. Also, the computation costs for a 400-sector table were estimated. The methodology may well become a standard part of the preparation and analysis of I–O tables that deal with energy or with more general I–O data.

In another project (RP670) the usefulness of net energy analysis is being examined. This analysis is a new and controversial approach to calculating the merit of energy technologies. The systems approach differs from conventional energy calculations in several respects. For example, it may include the energy content of steel, as well as other materials and labor used in constructing energy facilities. It may also include the metabolic energy of land or water resources used and displaced by energy facilities. (Public Law 93-577 requires ERDA to make net energy analyses of nonnuclear technologies on which ERDA does research and development; ERDA will also do net energy analyses on nuclear technologies.)

Net energy analysis has been attracting considerable attention among the public, scientists, engineers, and members of Congress. It is important that the value and limitations of this methodology be understood. Its uncritical application can give misleading results concerning electricity.

The contractor for the project, Criterion Analysis, Inc., is reviewing and critiquing relevant literature on net energy analysis. This review will include a discussion of various propositions on which net energy is based and of methodologies such as energy accounting, energy balance analysis, energy cost analysis, and energy budgeting.

The methodologies will be examined for their usefulness in analyzing new technology. Energy analysis and economic analysis will be compared and contrasted. The contractor will also identify methodological problem areas in these analyses, including time horizons, price systems, system boundaries (both economic and thermodynamic), and the quality of energy. *Project Manager: Rex Riley*

CROSS-SECTORAL STUDIES: LOAD FORECASTING

The cross-sectoral studies subprogram includes time-of-day and seasonal projects, regional studies, methodological inquiries, and miscellaneous projects that analyze energy demand and conservation problems affecting two or more sectors of the economy. The present report deals exclusively with time-of-day and seasonal load forecasting. It describes the underlying structure of our effort to develop load-forecasting models, the rationale for choosing this structure, and the methodologies that can be used to quantify and statistically validate the structure.

The forecasting effort has the following working guidelines:

- The principal focus of the effort will be within the next 10 to 25 years.

- The shape of the *entire* load curve will be under study; that is, kilowatt demand by time of day, week, and season. There are three important reasons to be concerned with the entire load pattern. First, the shape of the load curve is needed to determine the optimal mix of baseload, intermediate, and peak capacity. The fact that various types of capacity have different capital requirements and operating (or energy) costs makes the whole load pattern a subject of economic and financial interest. Second, the type of capacity influences the kinds of fuels that can be used. Third, analysis and forecasting of the impact of peak load pricing on the components of demand require forecasts of load pattern by customer class.

□ The load curve by customer class will be related to the economic and demographic structure. (In general, the accuracy of long-term forecasts is directly related to the level of disaggregation in the modeling structure.)

□ The program is not intended to produce short-term forecasts or replace efforts of individual utilities to forecast their own loads. Current state-of-the-art methods that take into account abnormal weather, irregular events (such as strikes, holidays, and industrial shutdown), and, most important, the average load pattern (that is, methods that range from informal trends, seasonal, and weather-rated decomposition to more formal time series analysis, such as Box-Jenkins), are probably adequate for short-term forecasts.

While the conjunction of time series methods and weather sensitivity modeling does quite well in the short term (0–5 years), the consensus is that it fails in the long term (10–25 years). Increasingly, utilities have turned to one form or another of engineering-economic or econometric models for mid- to long-range energy forecasts. As is well known, the success (in a statistical sense) of econometrically forecasting energy or kilowatt-hour demand is much greater than the success in forecasting peak demand.

Most econometric attempts have sought to relate load to various economic activity variables, to employment, and to population. Engineering-economic models undertake to aggregate consumption, utilizing engineering efficiency data for various uses in the different classes of service to get total load projections.

The poor performance of economic activity variables in forecasting peak load is a result of economic activity's being more closely related to utilization of energy-using equipment than to the equipment and its characteristics. Similarly, population and employment variables are more likely to be related to overall utilization, whereas the relevant variables affecting the temporal load pattern of utilization are family composition and adult employment status. On the other hand, the shortcomings of the engineering-economic approach in forecasting peak load are likely to be due to inadequate forecasting of the demand for energy-using equipment (investment) and stock of equipment of each specific type of energy use.

To see how the quantity and characteristics of specific types of energy-using equipment are related to the load pattern, let's consider the residential sector.

Residential Load Patterns

Here, as in other sectors, weather is a key load determinant. But weather impact on time-of-day and seasonal load depends crucially on the configuration of space-conditioning equipment owned and used by households. The experience of winter-peaking utilities' changing to summer-peaking with the advent of widespread refrigeration air conditioning attests to this. In the long run, to quantify the weather's impact on loads (both on average and in the extremes), we must have reliable forecasts of the stock of each type of household's heating and cooling system and the energy form it requires.

□ In residential load patterns, the multiple saturation of appliances, such as color TVs and refrigerators, and the introduction of new goods, such as electric automobiles, are likely to be quite important.

□ In both the residential and the commercial sectors, new building designs, ASHRAE Standard 90-75, insulation requirements, and space conditioning systems will be major determinants of load configuration.

□ In the industrial sector, the pattern of industrial composition, the extent of self-generation, the development of methods to reuse waste heat, and the level of interruptible demand are all likely to have major effects on load patterns.

Basically, the methodology that must be developed is an integration of time series analysis and econometrics. While that sounds appealing, it is not very enlightening unless we outline how this integration will be carried out. The high frequency of load curve data is both a blessing and a curse. While it gives the statistician an enormous amount of information, it is also heavily autocorrelated and has a serially correlated error structure. These problems by themselves would not be serious, since a combination of autoregressive and moving-average techniques (that is to say, Box-Jenkins) could take care of them.

The problem comes in when we note that even after time series analysis has reached its limit, the residuals are not white noise—they are functionally related to the underlying economic, environmental, and demographic structure.

Three Approaches

One of the most promising proposals for integrating time series and econometrics comes from Emmanuel Parzen, a well-known time series statistician from the State University of New York at Buffalo. He proposes to first purge the data of auto- and serial-correlation problems, then model the residuals econometrically. The time series techniques are termed "detrending" and "deseasonalizing," even though they may be applied at much finer divisions than the seasons. The residual model Parzen calls an "innovations filter." Thus we have the time series $Y(X, t)$, which is functionally related to exogenous variables X and time t, being reduced to the time series innovations $\epsilon(X, t)$, which is reduced to white noise $\epsilon(t)$ by the innovations filter.

$$Y(X, t) \rightarrow \boxed{\text{Trend filter}}\boxed{\text{Seasonal filter}} \rightarrow \epsilon(X, t) \rightarrow \boxed{\text{Innovations filter}} \rightarrow \epsilon(t)$$

An alternative to Parzen's approach is suggested by Roger Koenker of the University of Illinois at Urbana. His procedure is to fit a cubic spline to the load curve and estimate its parameters, or "knots." From these knots, the entire load curve can be approximated by piecewise continuous cubic polynomials. The knots are then fitted to economic and demographic variables of the users. Koenker's initial work was on aggregate residential load-using substation (or transformer) loads and census tract economic and demographic variables. We hope to get further experience with this technique by applying it to individual household data.

Another alternative methodology is to model demand econometrically at each time of day as a function of economic and demographic variables, then analyze the time-of-day pattern of the estimate coefficients. This approach is similar to one developed by Cargill and Meyer but will have considerably more sophistication in the treatment of the error structures. This rough approach will be developed to act as the frame of reference against which we can compare the forecasting performance of more sophisticated techniques. (For further information on these methodologies, see EPRI SR-31, *Proceedings on Forecasting Methodology for Time-of-Day and Seasonal Electric Utility Loads,* edited by James Boyd.)

Obviously, the load data to implement the structural approach will come from cooperating utilities, as will some of the microdata. For instance, Commonwealth Edison Co. is just completing an extensive time-of-day metering and household survey on 900 residential users. This survey and similar data should be very useful (in spite of the caveat that cross-section evidence cannot always be trusted in a time series forecasting application). Specific data on potential new equipment, like electric automobiles (RP758), heat pumps (RP137, RP432, RP483), and solar heating (RP385), are being developed in ongoing projects. Stock data on commercial buildings (RP662), transportation equipment (RP757), houses and household durables (RP431, RP576), and industrial processes (RP433, RP683, RP802) are already in the public domain or being developed coincident to our kilowatt-hour forecasting effort. *Project Manager: Anthony Lawrence*

ENERGY SYSTEMS MODELING PROGRAM

Technology Studies and Process Analysis

A major objective of the Energy Systems Modeling Program is a comprehensive representation of the basic economic and physical processes that affect energy supply and use. A related concern is to study the interaction between performance of the energy sector and that of the economy as a whole. One approach to energy systems modeling relies primarily on historical or cross-section data to derive equations that explain the behavior of the past and forecast the future. This is the econometric approach.

A second modeling methodology concentrates on the physical aspects of the energy system: the capacity constraints, efficiencies, and environmental residuals inherent in the hundreds of technological processes that make up the system. This is the process analysis approach. One of the most comprehensive efforts taking this approach is that being conducted by the Brookhaven National Laboratory's (BNL) Energy Technology Assessment Group. BNL has developed a set of Reference Energy Systems, as well as a linear programming model (BESOM, or Brookhaven Energy System Optimization Model) and a dynamic version of the linear model (DESOM, or Dynamic Energy System Optimization Model).

BNL's work in this area extends back to 1971 when it developed the Reference Energy Systems for the White House's Office of Science and Technology. This effort, continued and expanded in subsequent years, has been directed toward producing a methodology for the assessment of energy technologies. Under RP442, EPRI's Energy Systems Modeling Program is supporting the refinement and adaptation of the BNL models to meet EPRI's analytic needs.

For its models, BNL uses data derived from technology studies and process analyses. These data are designated the Energy Model Data Base. The data base contains information on all the processes that supply, transport, refine, convert, and use energy: for example, power generation by light water reactors, coal mining by room and pillar methods, and steel production by electric furnace. To define the energy system for a base year, each process is characterized by the amount of energy in Btus that flowed into the process—for example, the number of Btus of coal that went into coal-steam electric power generation. Also associated with the process is its primary efficiency, represented as a ratio of the Btu process output to the Btu process input.

The remaining process data are coefficients that describe —for each unit of energy that goes through the process—such elements as ancillary energy requirements by fuel type and all the important emissions factors for both water and air (including acids, bases, phosphates, particulates, sulfates, and hydrocarbons). Some coefficients account for nuclear radiation, nuclear wastes, population exposure, and health factors (occupational deaths and injuries, workdays lost, etc.). Economic coefficients describe the fixed, operating, and total costs. All these coefficients are defined in appropriate units per Btu flow through the process. The data base involves over 400 energy supply and 200 energy utilization processes. Each process is characterized by as many as 40 data elements, with allowance for up to 190 elements as new data are obtained from further technological studies and process analyses.

The quantification of these numerous energy system processes provides the basic building blocks for the BNL models. The BNL Reference Energy Systems are network representations of the energy flows required to meet a set of estimated demands. These flows originate with supply of the basic energy sources and extend through all the technological activities involved in satisfying the demands.

The Reference Energy Systems produce an inventory of environmental emissions, other first-order environmental effects, and the costs associated with all elements of the system. These measures are projected from a historical base year as yardsticks from which to gauge the relative impacts of introducing alternative technologies. To make this kind of comparative analysis more realistic and useful, it should be done on a regional basis. Under RP442, EPRI is supporting the disaggregation of the existing national version of the Reference Energy Systems into regional components.

BESOM is a static linear programming model that has been used to suggest feasible and least-cost mixes of available competing energy technologies. DESOM, the model's dynamic version, allows for the introduction of time-related variables, such as rate of growth of new capacity, prices, and resource depletion, to identify the alternative energy systems that minimize the discounted cost of energy over time. The dynamic feature of DESOM makes it particularly useful in assessing the optimal timing and rate of implementation for new technologies under a variety of economic, technological, and environmental assumptions. RP442 provides for the continued development, refinement, and adaptation of DESOM to EPRI specification. *Project Manager: Ron Michelson*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

UNIVERSITY RESEARCH

A broad-base university research program provides essential research support for meeting the objectives of the Fossil Fuel and Advanced Systems Division. University research is a resource used by all four departments in the division. It includes a wide range of activities—from a study on electrostatic precipitator plate rapping and reliability to studies on advanced fueled fusion reactors suitable for direct energy conversion. Altogether, 52 university research projects totaling $11 million are underway, representing 23% of the projects presently authorized in the division.

Near-Term Projects

The involvement of universities in near-term applied research covers a number of areas of direct importance to the electric utility industry. For example, a low-pressure cascade impactor for measuring size distribution of particles emitted from coal-fired utility boilers has been developed under an EPRI instrumentation program. A number of EPRI projects are directed toward improved electrostatic precipitator operation and reliability. A related project is concerned with improving the theoretical understanding of particle motion in such removal systems. Another project is identifying, both theoretically and experimentally, the roles of turbulent mixing and chemical reactions when pulverized coal is fed into a combustion chamber or a high-pressure gasifier. The performance, economics, and reliability of a cooling tower–cooling pond mix and the appropriate geographic regions of the U.S. where the mixed-cooling concept might be employed were evaluated for EPRI by university investigators. These projects, and others like them, indicate a growing awareness by university investigators of present utility problems.

Midterm Projects

A number of EPRI university projects are providing supporting data and analysis techniques for midterm alternative fuel sources, advanced energy conversion techniques, and energy storage capabilities. One project is on panel-bed filter development, with the objective of cleaning the hot fuel gases from coal gasifiers before they are burned in high-temperature gas turbines. High-expansion foams are also being explored for submicron particle emission control. Other particulate removal projects include the development of new agglomeration and collection procedures for electrostatic precipitators, the characterization of fly ash, and the evaluation of resonant acoustic techniques for enhancing the agglomeration of micron-size particles.

A significant university effort, funded and directed by EPRI, is investigating synthetic clean liquids and solids. The projects range from the characterization of coal slurries and the analysis of coal liquid products for molecular composition, ash characteristics, and phase equilibria to the measurement of vapor pressures, viscosities, and volumetric behavior for coal liquefaction processes. These projects provide a closely coordinated data support effort for the main EPRI liquefaction program.

In the area of energy storage, EPRI participation in university research includes the development of improved beta alumina electrolytes for advanced storage batteries and a project to identify improved beta alumina fabrication techniques. Projects are underway in the area of improved fuel cell cathodes with minimum amounts of precious metals and in technical and economic evaluations of thermochemical hydrogen production. This latter project is also related to the synthetic clean liquids and solids program and has coupled the technical expertise of a university researcher with the cost-estimating capabilities of an architect-engineer.

The electric utility industry and EPRI have maintained interest in coal-fired magnetohydrodynamic (MHD) production of electric power. A major university effort is underway to evaluate coal slag deposition phenomena in open-cycle coal-fired MHD generators, an important concept for protecting the channel walls. This project will yield data on slag formation, flow characteristics, magnetic and electric behavior, and heat transfer characteristics in coal combustion environments that simulate full-scale unit operations.

A relatively large university effort is directed toward the evaluation of the heat transfer characteristics for steam generating tubes immersed directly in a fluidized bed. Other efforts in this area include the reduction of inorganic sulfur in dry pulverized coal through the use of high-intensity magnetic separation.

Long-Term Projects

For the long-term effort to develop new energy sources, an extensive EPRI program is underway in magnetically confined and inertially confined fusion research. These projects range from those initially supported under ERC auspices to newer projects for conceptual design studies of laser-initiated, inertial confinement fusion. Safety and environmental effects of central station fusion power are also being evaluated. The utility systems' interface with fusion reactors is being explored by a team composed of an architect-engineer and representatives from a university and a national laboratory. The objective of these university-based fusion projects is the achievement of commercial power from fusion energy sources earlier than would otherwise occur.

University Research Versus Industrial R&D

The specific objectives and needs of the EPRI project manager and the university principal investigator occasionally may conflict.

University principal investigators usually submit proposals that reflect their personal interests and capabilities in a given technical area. Industrial sponsors must recognize that university research is oriented toward more fundamental and broader problems than those covered by the tightly structured work statements of the typical industrial R&D contract. The best project performance is achieved when the principal investigator is enthusiastically committed to the scientific and technical objectives of the project. Also, the freedom of thought exercised by the university investigator could lead to unexpected but very important results. Creativity, innovation, and the education of technically trained personnel required by the electric utility industry in the future are important benefits derived from university research in addition to the reported project results. Therefore, we in the utility industry must continue to use the extensive technical resources of the universities.

University Curricula

Following Sputnik in 1957, there was a considerable infusion of additional mathematics, modern physics, and humanities into the undergraduate engineering curricula, thus lengthening academic programs for engineering students. When a decrease in engineering enrollments occurred in the late 1960s, engineering schools eliminated a number of courses from their curricula, thus becoming more competitive with other majors in universities. Significantly, the courses eliminated dealt largely with engineering practice (engineering drawing, power plant design, machine design, electrical machinery design) and courses in communication (English composition and report preparation). It is precisely in the area of engineering design that significant problems have arisen in the utility industry.

Over the past few decades university graduate and research faculties that rely largely on research funding for their existence have grown considerably. These faculties respond to sources of funding primarily in terms of the objectives set by the funding agencies rather than in terms of the needs of the undergraduate curricula or the engineering community that provides services to the utility industry.

An interesting result of this pattern of funding is that a large reservoir of highly trained talent is available in such high-technology areas as plasma physics for controlled thermonuclear fusion, spectroscopic analysis of chemical systems, and solid state physics. A major national and international effort is underway, both theoretically and experimentally, to bring about laser-initiated, inertially confined thermonuclear reactions with sufficient energy output to be classified as energy break-even.

However, a similar effort is not expended in the area of pulverized coal combustion for steam generation. This is the fundamental physical process on which the nation's fossil fuel energy conversion to electric power is to be based over at least the next quarter century. The reliability and performance of these systems have been decreasing as environmental controls have become more stringent and fuel quality has decreased. And yet there are fewer than a dozen university principal investigators working on fundamental processes of coal combustion in boiler environments.

Although the need for new information is great, the universities are moving to sources of funding in other areas and are not providing for research in coal utilization. Both EPRI and ERDA recognize the need in this area and are trying to instigate research in the broader area of direct fossil-fuel-fired power systems.

Synergistic Relationships

It should be recognized that the university research environment provides a setting for reflective analysis of processes that is not usually maintained in the industrial community. For this reason, university research can lead to an improved understanding of the physical phenomena occurring in a given process. Fundamental data can be taken in controlled environments, which can lead to better analytic design tools for full-scale application. Very rarely, however, will university research provide specific design solutions for demonstration or full-scale units.

By recognizing the particular characteristics of university research, EPRI serves as a bridge between the university research community and the engineering community, which provides technical solutions and services to the electric utility industry. EPRI support provides an appropriate focus and direction for university research, bringing to the university a greater awareness and need for engineering precision and excellence. In return, the utility industry will continue to benefit through new concepts, the acquisition of fundamental data and understanding, and the assurance of a stronger foundation for technical personnel who will be required to meet the future electric energy needs of the nation.

SOLAR–THERMAL ELECTRIC POWER

In solar-thermal electric power plants, concentrated solar energy is converted to thermal energy and transferred to a working fluid for use in conventional Rankine or Brayton cycle turbine generators.

Two general classes of solar-thermal conversion systems are the central receiver and the distributed receiver. In a central receiver system, solar energy is optically focused by a large array of two-axis tracking mirrors (heliostats) onto a central receiver or heat exchanger that is located on top of a large central tower. Solar energy concentration ratios from 1000 to 2000 are possible and temperatures of 1000–2000°F can be produced at the receiver for use in the turbines. In distributed systems, solar energy is directly converted to thermal energy and transferred to a fluid at each individual collector. The fluid is then pumped through an extensive network of insulated pipes to a centrally located turbine generator plant. The collector and tracking options that have been investigated include two-axis tracking paraboloidal dish collectors, single-axis tracking parabolic trough collectors, stationary or seasonally adjusted flat plate collectors, fixed hemispheric mirrors with movable receivers, and fixed cylindrical mirrors with movable receivers. Because of the different concentration ratios of these various concepts, receiver temperatures range 200–950°F. A comparison of these concepts is given in Table 1.

Recent analyses indicate that solar-thermal electric power plants will be most competitive when used to meet intermediate load requirements, displacing conventional power plants using scarce oil and gas. Also, their application will probably be limited to the southwestern U.S., a region with high direct insolation. Current estimates indicate that the central receiver concept delivers the lowest busbar energy costs of the alternatives considered. This is due to three factors:

- The higher receiver temperatures result in more efficient conversion of solar energy to electric power and smaller mirror areas per rated electric power output.

- The optical transmission of the solar radiation to the central receiver eliminates the high costs of insulated pipes required by the distributed system.

Table 1

ALTERNATIVE SOLAR-THERMAL CONVERSION CONCEPTS

Distributed Receiver Collector	*Tracking Requirement*	*Operating Temperature (°F)*
Flat plate	None	100–270
Augmented flat plate	None or single axis	200–500
Parabolic trough	Single axis	400–1200
Paraboloid	Two axis	500–2000
Central Receiver Collector	*Tracking Requirement*	*Operating Temperature (°F)*
Flat mirror	Two axis	500–1000
Focused mirror	Two axis	500–2000

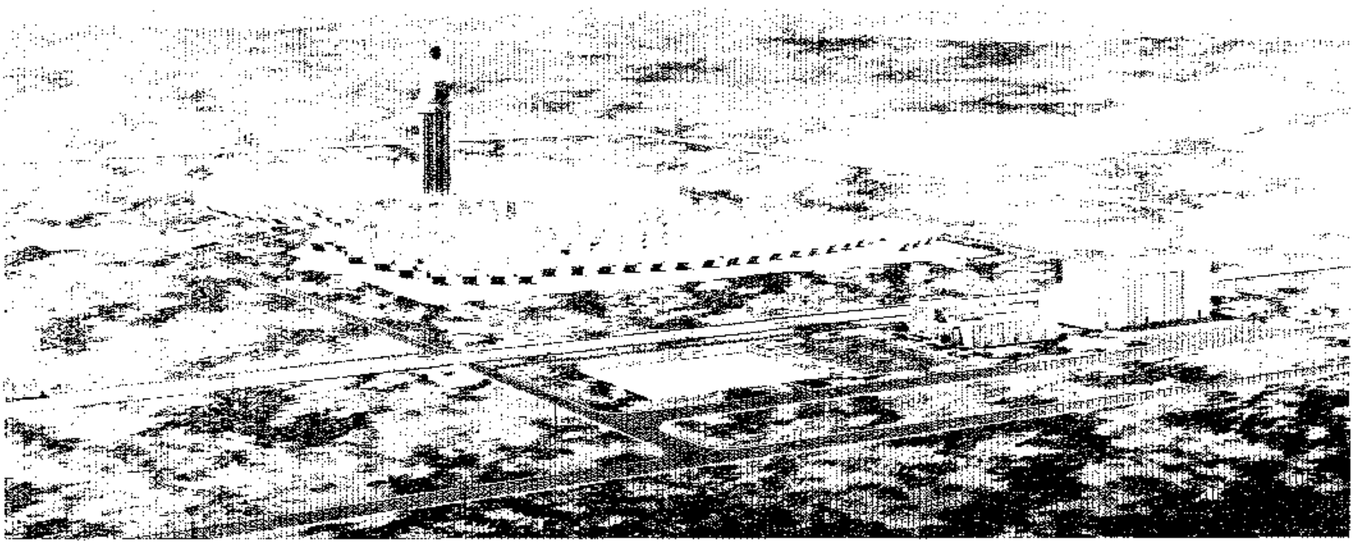
- The large central receiver uses a more efficient and lower-cost heat exchanger. (The multiple heat exchangers used by distributed collectors often require selective coatings and vacuum envelopes to efficiently absorb solar energy and to minimize thermal losses.)

Solar plants have not only unscheduled outages due to component failures but also unexpected outages caused by cloud cover. In order for solar-thermal conversion power plants to have potential for capacity displacement, energy storage is required to meet the electric load requirements. The storage options considered to date include thermal storage and the use of fossil fuels to operate these plants in a hybrid mode. For the preferred intermediate-load applications, six hours of storage is needed to meet the reliability requirement that loss-of-load not exceed one day in ten years.

Preliminary studies indicate that because of reliability requirements stand-alone solar-thermal power plants may be limited to 15–20% of the generation capacity in a utility network. Solar plants must therefore be viewed as complementary to baseload plants.

Recent economic analyses project busbar costs (1975 dollars) for 100-Mwe systems as 40–60 mills/kwh for the central receiver, 70 mills/kwh for the paraboloidal dish, and 100 mills/kwh for the parabolic trough systems. These cost estimates are for intermediate load applications, including six hours of storage. The central receiver energy costs are based on a heliostat cost of $7/ft^2$, a 30-year plant life, and an operating and maintenance cost of 3 mills/kwh. Total central

Figure 1 The ERDA program is building a 5-Mwt test facility in Albuquerque, New Mexico, and expects to be operating a 10-Mwe central receiver pilot demonstration plant by 1980.



receiver power plant costs, including interest during construction, are estimated at $1300/kwe for central receiver plants with six hours of storage and at $1000/kwe for hybrid central receiver plants (using fossil fuel backup). The most likely power ratings for these central receiver plants are 50–200 Mwe.

The central receiver concept is being pursued vigorously by both ERDA and EPRI. Three teams are presently under contract to ERDA for the preliminary design of a 10-Mwe central receiver pilot plant, using a water-cooled central receiver to produce steam at 950°F for input to a conventional Rankine cycle turbine generator. The pilot plant will incorporate six hours of thermal storage. The balance of plant, including a cooling tower, is expected to be provided by the utility industry.

Because the solar-thermal conversion power plants must be sited in the arid regions of the southwestern U.S., the complementary EPRI program is evaluating two alternative, second-generation, gas-cooled, Brayton cycle central receiver concepts that do not have large cooling water requirements. Work on a closed-cycle helium receiver operating at 1500°F is being performed by the Boeing Aerospace Co. (RP377). Black & Veatch Consulting Engineers is investigating the technical and economic feasibility of an open-cycle receiver that would operate at 2000°F (RP475).

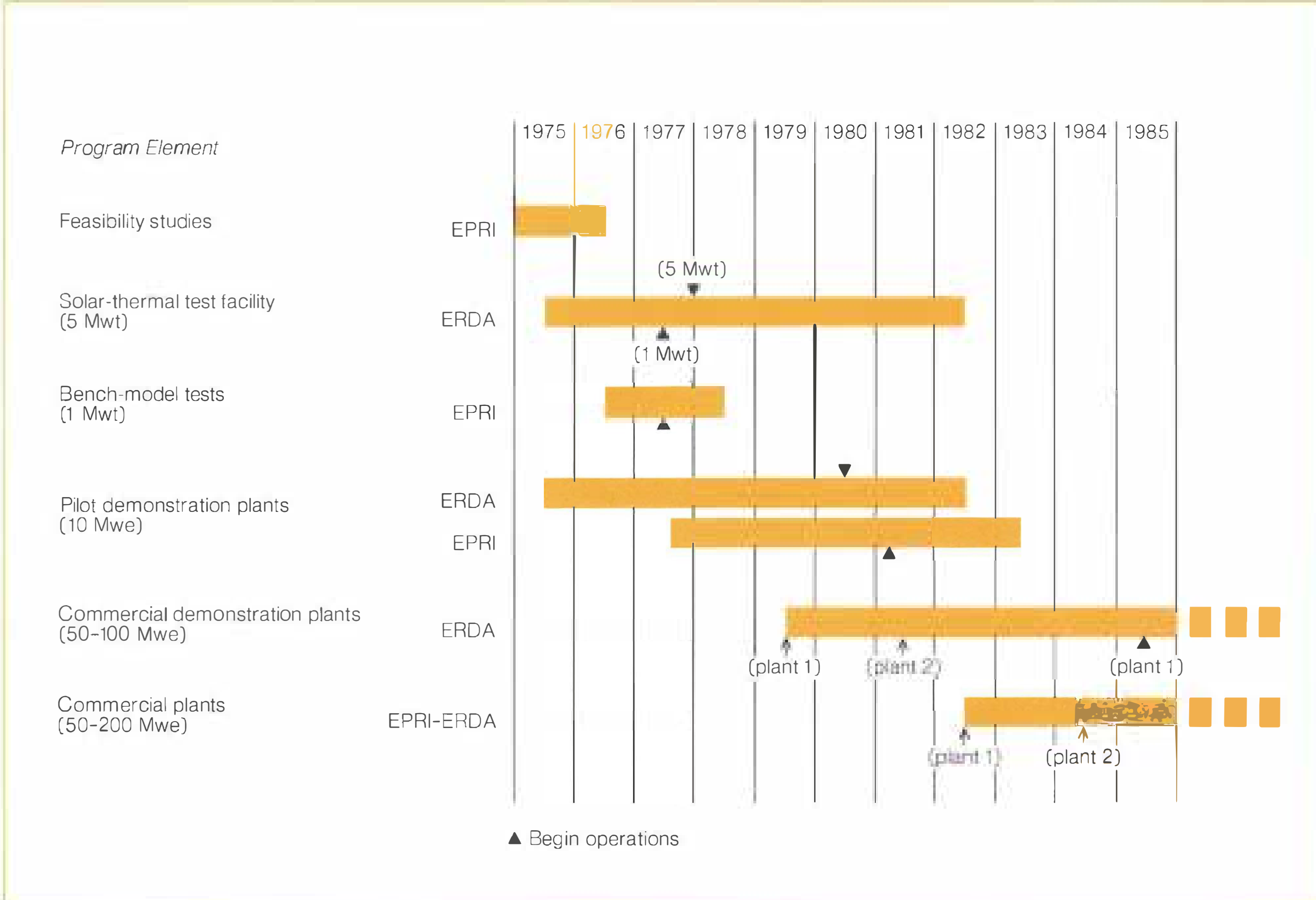
Brayton cycles require higher temperatures than Rankine cycles and place a heavy burden on the materials used in the receiver. In addition, the intermittent nature of solar energy presents major technical and material problems. All solar-thermal systems must accept diurnal transients and rapid transients from cloud passes during daily operation. Over a period of 30 years the receiver will be subjected to more than 10,000 diurnal cycles and probably two or three times this number of transients.

Boeing has subjected two receiver material candidates, Haynes 188 and Inconel 617, to extensive thermal cycling tests. The thermal cycle range was 900–1525°F, with approximately two minutes at the maximum temperature, for 10,500 cycles at 500 psi helium pressure, the equivalent of 30 years of diurnal cycling. Black & Veatch has started thermal cycling tests on ceramic heat exchanger materials, silicon carbide and cordierite, with temperatures up to 2300°F and pressures of 100–200 psi.

The Boeing concept will use a closed-cycle helium turbine. The flexibility of the closed-cycle system allows the solar-thermal electric plant to load-follow at a high efficiency and still maintain a steady heat output. The Black & Veatch concept will use a conventional open-cycle air turbine.

In follow-on studies both concepts will be carried forward through a 1-Mwt bench-model receiver design, construction,

Figure 2 Proposed schedule and milestones for both the 1-Mwt bench-model test and the 10-Mwe pilot plants. The date of operation of the EPRI pilot plant coincides closely with that of the proposed ERDA pilot plant scheduled for test operations in 1980. Commercial operation is expected in the early 1990s.



and test phase. Subsequent to the 1-Mwt bench-model tests, one of these concepts will be selected for demonstration in a 10-Mwe (equivalent) gas-cooled central receiver pilot plant.

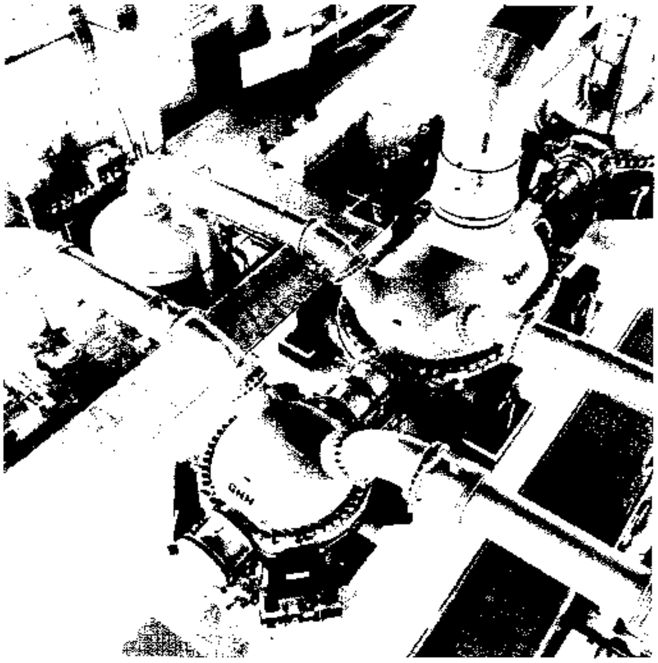
The proposed pilot plant may use the Solar Centaur regenerative gas turbine that is rated at 2.7 Mwe. The firing temperature for this turbine is 1600°F, which represents a conservative test for the receiver design at this power level. A 10-Mwe (equivalent) has been designated because the pilot plant is sized for 10-Mwe operation. However, to minimize cost, the plant will use only one quadrant of the field of heliostats (north field) and one quadrant of the 10-Mwe-scale receiver.

This 10-Mwe (equivalent) pilot plant demonstration program is a logical extension of the current EPRI program and is a complement to the 10-Mwe water-cooled central receiver pilot plant concept planned by ERDA.

EPRI is also sponsoring studies on distributed solar-thermal systems (e.g., the fixed-mirror, distributed focus concept) to ensure that no potential source is overlooked. Two concepts are attractive as potential alternative systems. They have one common feature, a fixed mirror. The first concept (RP548, Helio Associates and E-Systems) uses a stationary hemispheric collector lined with mirrors. Such a collector has a movable line focus. A movable central receiver tracks the focus. The second (RP739 with the General Atomic Company) examines a fixed-mirror, cylindrical trough concept. This system uses a tracking line receiver. Three western utility companies are supporting a test module demonstration of this particular concept, and an EPRI-funded systems study complements the utility program.

The capital-intensive nature of solar power plants, coupled with their inherently low reliability, will present a significant obstacle to widespread market penetration. Closely related is the requirement for component system lifetimes of 25–30 years, with operating and maintenance costs low enough to produce competitive busbar energy costs. Some of these

Figure 3 The helium turbine installation at a commercial power plant owned and operated by Energieversorgung, Oberhausen, Germany. The turbomachinery and associate heat exchangers were built by Gutehoffnungshütte, Sterkrade, Germany.



issues, as well as the margin requirements of solar-thermal conversion power plants, are being studied by Westinghouse under RP648, Requirements Definition and Impact Analysis of Solar-Thermal Power Plants.

The environmental impacts of solar-thermal systems must also be assessed. These systems require large land areas, approximately one square mile for a 100-Mwe output. Land use displacement and cooling water availability must be considered, as well as surface control requirements, microclimatic changes, effects on desert microflora, and the energy and resource requirements for producing large solar plants. The environmental impact of solar power plants is being addressed under two contracts, RP551-1 with Black & Veatch and RP551-2 with Woodward-Clyde Consultants. *Program Manager: Piet B. Bos*

HEAT REJECTION

The thermodynamics of power generation require that heat be rejected from power plants in large amounts at close to ambient temperature. Once-through cooling has been the preferred technology, having both the lowest initial cost and the highest average plant efficiency. However, the Federal Water Pollution Control Act of 1972 and subsequent Effluent Limitations, Guidelines, and Standards have mandated in nearly all cases the use of "evaporative external cooling to achieve essentially no discharge of heat, except for cold side blowdown in a closed, recirculating cooling system." This requirement will be met with limited use of once-through cooling, but primarily with closed-cycle cooling ponds and lakes, spray ponds and canals, and mechanical- or natural-draft wet cooling towers. These systems warm or evaporate large quantities of water, impose one of the major constraints on power plant siting, constitute a significant component of the plant capital costs, and have a dominant influence on the overall plant design and heat rate.

EPRI's Water Quality Control and Heat Rejection Program has the responsibility of ensuring that utilities have the technology to meet their cooling requirements in a cost-effective and environmentally acceptable manner. The highest priority objectives have been defined as:

- Minimization of cooling water requirements
- Development of minimum total evaluated cost systems
- Prediction and mitigation of cooling system environmental impact

Water Conservation

In 1971 the total average withdrawal rate of fresh water for power plant cooling was reported to be 9% of the average annual runoff of all streams in the conterminous 48 states. All conventional cooling systems consume approximately the same amount of water, on the order of 10^6 kg/hr for a 1000-Mwe plant. While sensible heating of the air accounts for some of the cooling in sprays and towers, the relative rates of sensible and latent cooling are governed by analogous heat and mass transfer processes, and the designer has limited flexibility in shifting the heat load toward sensible cooling. Therefore, water conservation alternatives are limited to dry cooling to the atmosphere or the use of waste water for evaporative system makeup.

Dry Cooling

Dry cooling is technically achievable today. A small (22 Mwe), dry-cooled, mine-mouth unit at the Black Hills Power and Light plant in Wyodak, Wyoming, has been in operation since 1969. A 330-Mwe dry-cooled unit is under construction at the same location. A few dry-cooled plants are in operation in England, Europe, the USSR, and South Africa. The major drawbacks to dry cooling are the high initial capital cost, the reduced average plant efficiency, and the severe capability penalties incurred during periods of high ambient dry bulb temperatures that often coincide with peak load periods.

A study of an advanced dry-cooling tower system at the Linde Division of Union Carbide to incorporate high-performance heat transfer surfaces with a phase-change fluid (ammonia) in the condenser-tower loop is underway. Comparative cost studies of preliminary designs show promise of 15–20% savings in present total evaluated worth and 20–25% savings in the initial capital cost over conventional dry tower technology. Future plans for development and demonstration of the system are being coordinated with the ERDA dry-cooling tower development program.

Wet-trimmed dry systems have been designed to 5–10% of the annual water consumption of all wet towers, with substantial cost savings over all dry systems. The first utility commitment to a wet-dry system has been made by Public Service of New Mexico at its San Juan plant. Potential difficulties include operation and control problems in shifting from wet to dry modes, definition of the optimum operating strategy for minimum water consumption at maximum plant efficiency, and anticipated maintenance problems associated with alternate wetting and drying of heat transfer surfaces in some of the proposed tower configurations.

EPRI is initiating a project with Southern California Edison to field-test a wet-dry tower at an operating plant. A single wet-dry cell will be installed in parallel with the existing wet tower system and operated for one year to verify tower performance and water consumption models and to obtain in-plant experience with the operating, maintenance, and control problems.

Reclamation of Waste Water

The high cost of dry cooling makes an investment in waste water reclamation facilities to be used with wet towers a feasible approach to water conservation.

EPRI, along with the California Department of Water Resources, the Los Angeles Department of Water and Power, Pacific Gas and Electric Co., and Southern California Edison Co., is funding a project at the University of California at Berkeley to demonstrate the use of agricultural runoff water from the irrigation drainage systems in the San Joaquin Valley for cooling tower makeup. The process includes softening of the waste water in an ion-exchange column, feeding the softened stream to the cooling tower as makeup, and concentrating the tower blowdown in a vertical tube evaporator for use as a regenerant for the ion-exchange resin. This is being tested at the component level and will be demonstrated in a 2000-gal/day system, using agricultural waste water. The problem of the ultimate disposal of the concentrated regenerant will be studied in a coordinated project by the Environmental Protection Agency.

Total Evaluated Costs

Within the overall constraints of water availability and environmental acceptability, cooling systems are selected on the basis of minimum total evaluated cost. Numerous comparisons of total evaluated costs and their breakdown for alternative cooling systems at a given base plant, location, and load projection have been presented. Table 2 gives a typical result for a 1000-Mwe baseload fossil-fired plant in a climatic location comparable to Philadelphia, Pennsylvania. The design of each cooling system has been fixed by optimizing at minimum total evaluated cost. Table 3 shows the breakdown of the total evaluated cost for five of these systems.

The results show that the energy and capability replacement costs dominate the total evaluated cost and hence the determination of the optimum design. The magnitude of these components of the total evaluated cost is directly related to assumptions as to how the magnitudes of the capability and energy deficits are evaluated and how the methods and costs of making up these deficits are assigned. The proper methodologies and assumptions are universally accepted and, in fact, have been a subject of much controversy in the field. Differences in assumptions are often implicit in the published studies and make it difficult to compare the results. A clear understanding of the effects of the choice of assumptions

Table 2
COMPARATIVE TOTAL EVALUATED COSTS

Cooling System	*Total Evaluated Cost** *A*†	*B*‡
Once-through	14.0	—
Cooling pond	42.2	—
Spray canal	31.8	—
Wet tower		
Mechanical draft	29.1	34.1
Natural draft	31.8	32.3
Dry tower		
Mechanical draft	84.0	113.8
Natural draft	80.0	108.7
Wet-Dry (mechanical draft; 10% water consumption)	—	75.2

*Compiled from WASH-1360, prepared by United Engineering and Construction for AEC. December 1974 (A), and for ERDA, August 1975 (B).
†1000 Mwe, fossil-fired, baseload (75% capacity factor), Philadelphia, Pa.
Plant life: 40 years
Annual fixed-charge rate: 15%; Interest rate: 8%
Year of pricing: January 1973
Capacity replacement: Gas turbine peaking units @ $150/kw
Energy replacement (auxiliaries and back-pressure variations): 8.5 mills/kwh
‡Same as A, except for the following data.
Year of pricing: July 1974
Energy replacement: 17 mills/kwh

Table 3
TOTAL EVALUATED COST BREAKDOWN*

Cost Component	*Cost ($million)*				
	Wet Tower (mechanical draft)	*Wet Tower (natural draft)*	*Dry Tower (mechanical draft)*	*Dry Tower (natural draft)*	*Wet-Dry Tower (10% water use)*
Capital cost	21.5	23.4	30.3	38.0	37.2
Capability replacement penalty	1.75	2.97	17.6	17.7	8.20
Energy replacement penalty	−1.4†	−2.21†	47.2	47.1	7.61
Capitalized annual cost of tower operation	3.27	—	11.5	—	11.4
Capitalized annual cost of water circulation operation	7.58	7.27	3.78	4.0	7.02
Capitalized annual cost of water makeup and treatment	0.18	0.17	—	—	0.02
Capitalized annual cost for operation and maintenance	1.23	0.67	3.39	1.94	3.74
	34.1	32.3	113.8	108.7	75.2

*Basis: Table 2, Col. B.
†Negative values indicate energy credits for turbine back pressure below design baseline.

on the final result is essential both for utility planning and design and for EPRI's research planning and concept evaluation.

To this end EPRI, in cooperation with ERDA, is planning a workshop to be attended by utility planners and design personnel, equipment vendors, architects and engineers, and researchers. The participants will discuss and evaluate the penalty assessment assumptions. A preworkshop technical planning study has been initiated to provide parametric studies and sensitivity analyses for ranges of penalty assessment assumptions. This will identify the important issues and provide a structure for workshop discussions. Following the workshop, a computer program will be developed to generate total evaluated cost comparisons with all important penalty assessment methodologies available as input. This code will be readily adaptable to the consideration of heat rejection systems for all baseload plants of current interest (fossil, nuclear, LWR, LMFBR, HTGR) and for advanced systems (solar, geothermal, fusion, MHD, and combined-cycle).

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

LOW-SODIUM COEFFICIENT LMFBR CORES

Analyses of hypothetical accidents in large LMFBR cores have shown that one of the principal modes of reactivity addition during such accidents is due to the voiding of the sodium coolant from the core. Reduction of the value of the positive Na void coefficient to near zero would limit this mode of reactivity addition to the core and may eliminate consideration of potentially troublesome scenarios.

Recent work (*1, 2*) indicates that by rearrangement of core and blanket material in a PuO_2-UO_2-fueled LMFBR it may be possible to reduce the value of the positive Na void coefficient while maintaining or improving the breeding gain. One such conceptual core design has been investigated in work performed at EPRI. Another method of achieving the same objective is by employing thorium-based fuels in the core.

The conceptual design for the PuO_2-UO_2-fueled LMFBR core is based on the seed-blanket modular-subassembly concept used also in the light water breeder reactor core. These special subassemblies shown in Figure 1 contain a PuO_2-UO_2 fuel region surrounded by a depleted UO_2 blanket region. In the core arrangement, the inner core contains these special subassemblies and the outer core contains conventional fuel subassemblies.

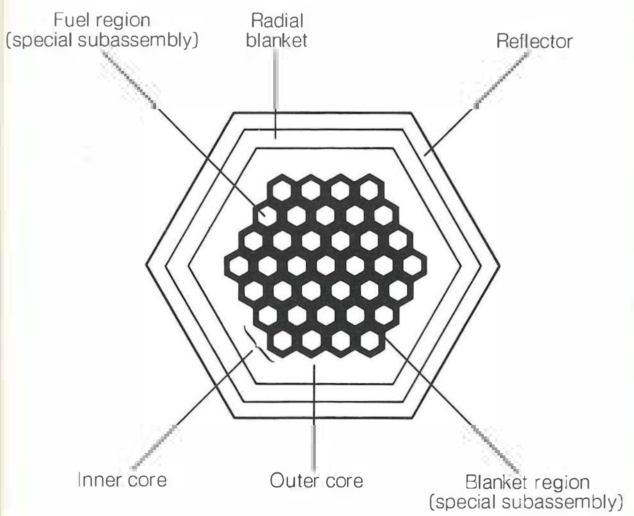


Figure 1 A conceptual design of the PuO_2-UO_2-fueled LMFBR core shows the special subassemblies in the inner core containing PuO_2-UO_2 fuel regions surrounded by depleted UO_2 blanket regions. The outer core contains conventional fuel assemblies.

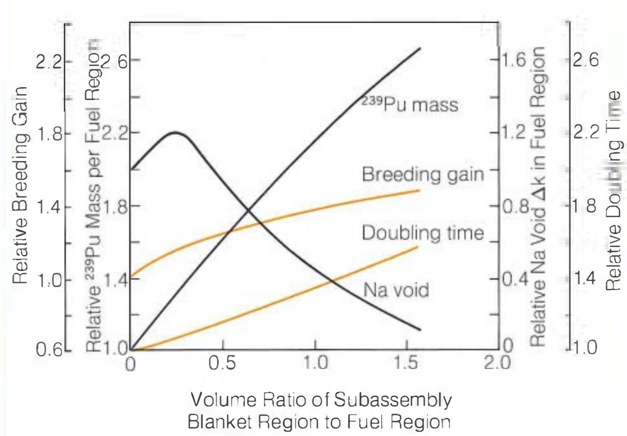


Figure 2 Four curves show the results of three-dimensional cell-type neutronic calculations performed for special subassembly with fuel region of ~82 liters and varying thickness for the blanket region.

Three-dimensional cell-type neutronic calculations were performed for a special subassembly with a fuel region of ~82 liters and varying thickness for the blanket region. The results are also shown in Figure 2. We find a substantial reduction in the Na void reactivity accompanied by a substantial increase in core inventory and a significant increase in the doubling time. When compared with those for a reference uniform core, results of calculations (including burnup) for core arrangements with special subassemblies show that with some increase in core inventory and doubling time, it may be possible to reduce the positive Na void coefficient.

LMFBR cores fueled with ThO_2-PuO_2 or thorium metal alloys have potential for reducing the positive Na void coefficient or even making it negative. Results of a set of calculations for the Na void (impact of void on reactor) variation as a function of radial and axial distance from the midplane of a uniform core are shown in Figure 3. The comparison with the reference PuO_2-UO_2 core shows that the peak void worths for the ThO_2-PuO_2 and for the Th-^{233}U-Pu metal-alloy-fueled uniform cores are respectively −20% and −25% of that for the reference PuO_2-UO_2-fueled core. By comparing the Na void Δk and other physics parameters, we find that it may be possible to achieve high breeding gains along with very favorable Na void characteristics if thorium metal alloys are used to fuel large LMFBRs.

The core design with the seed-blanket-type PuO_2-UO_2-fueled subassemblies may pose some thermal-hydraulic difficulties since the blanket regions have a large power-density swing during a burnup cycle due to the plutonium buildup. Consideration of LMFBR cores with thorium-based fuels would require an extensive development effort since hardly any experience with these fuels in fast reactor environments has been accumulated. *Program Manager: Bal Raj Seghal*

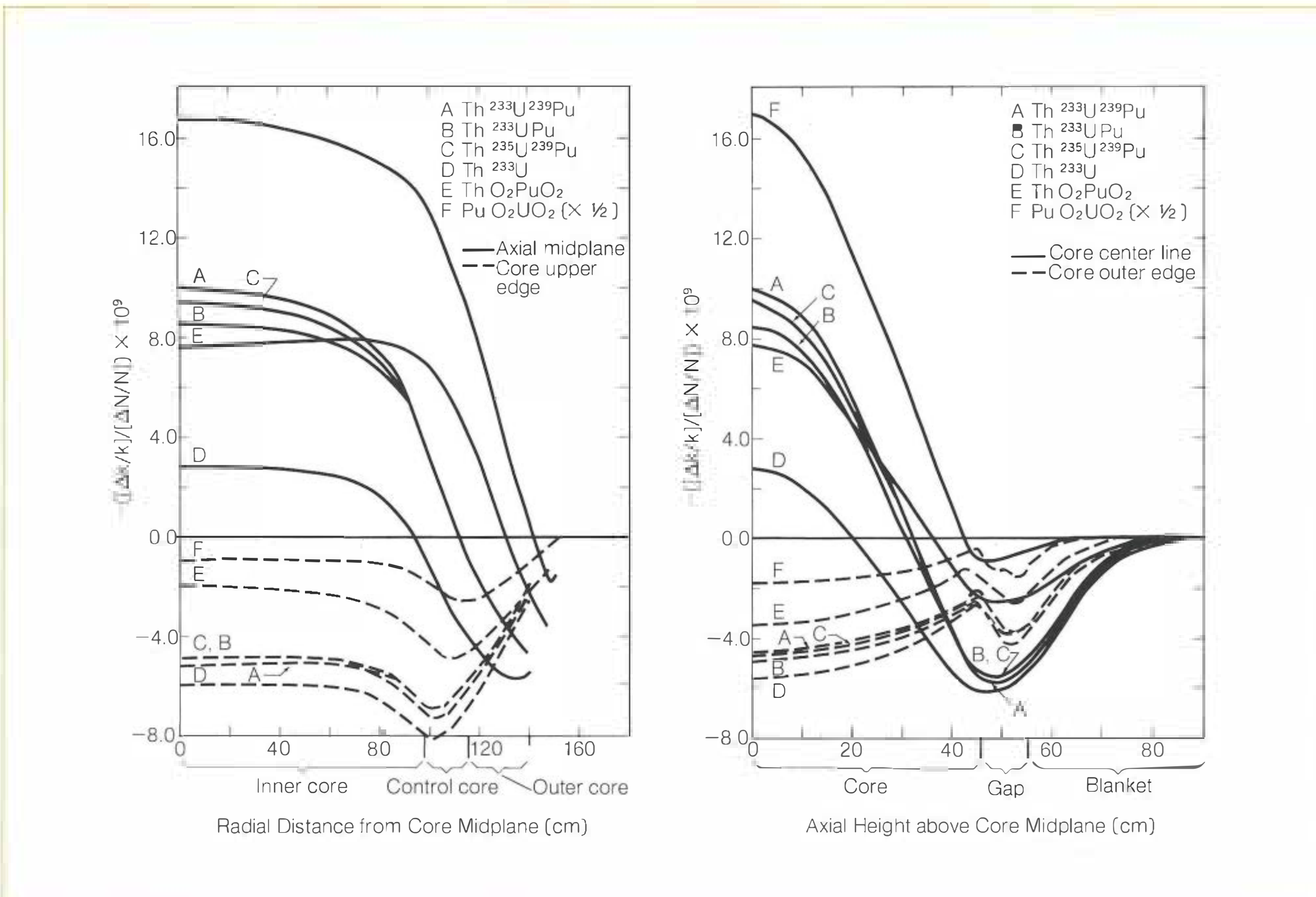


Figure 3 The Na void worth variation as a function of both radial and axial distance from the midplane of a uniform core.

REFLOOD HEAT TRANSFER PROGRAM

A loss-of-coolant accident (LOCA) is one in which most of the coolant water is expelled from a reactor. While a LOCA is not expected to occur at any time during the operation of the reactor, the reactor design includes an emergency core cooling system (ECCS) that would replace the coolant if it were lost.

In a PWR the reflood phase of a LOCA is the entire time period during which the emergency core cooling water rises from the bottom to the top of the core. Several large-scale experimental programs related to LOCA and to reflood are underway in the U.S. and abroad. The results from these experiments are gradually filling in the existing gaps in knowledge.

To date, the primary data source for reflood analysis has been the PWR–FLECHT (full-length emergency cooling heat transfer) tests performed on a 100-rod bundle at Westinghouse Corp. (partially funded by EPRI under RP287). It is the correlation of these data that is used in safety calculations to establish the adequacy of the ECCS.

It is the goal of the EPRI reflood program to develop an adequate and reliable analytic description of reflood heat transfer and fluid flow phenomena so that safety calculations may be made without reverting to arbitrary conservative assumptions or being required to provide directly applicable data for each case being analyzed. RP248, An Analytical and Experimental Study of Reflood Heat Transfer, being conducted by the University of California, Berkeley, is structured with these goals in mind.

The analytic goal of RP248 is to construct a calculation model capable of predicting the local flow conditions along the bundle and the distribution of heat transfer coefficients on the basis of the calculated local conditions. A single-tube experimental program is being conducted in support of the analytic work to provide basic reflood data, such as entrainment, which are unavailable from previous reflood experiments.

To understand the entire reflooding process, several complex heat transfer regimes must be understood and modeled. It is the goal of RP688, Investigation of Transition Boiling, being conducted by the University of Cincinnati, to provide experimental data and analytic modeling of one of those regimes. This project could provide important input to the ongoing analytic effort under RP248.

EPRI is conducting in-house analytic work to model reflood hydrodynamics. When combined with the heat transfer modeling under RP248, it is hoped that this effort will provide a tool for predicting the flow oscillations and steam-binding effects that have been observed in reflood experiments.

In addition to understanding present ECC systems, EPRI is studying alternatives that may prove more effective than the existing systems. Under RP341, Combined ECCS Injection Experimental Program, State University of New York at Buffalo is undertaking an initial examination of one such alternative. Top and bottom combined injection experiments will be conducted on a 9-rod bundle. In addition, the scope of RP347 with Creare, Inc., includes an evaluation of various alternative ECCS schemes. *Project Manager: Rodney R. Gay*

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R&D Status Report
TRANSMISSION AND DISTRIBUTION DIVISION

John J. Dougherty, Director

UNDERGROUND TRANSMISSION PROGRAM

The Underground Transmission Program is designed to respond to both the short- and the long-term requirements of the utility industry, with emphasis on the short-term (i.e., the 1975–1985 period). Problems related to rights-of-way acquisition, environmental impacts of overhead transmission lines, and the conservation of natural resources are the primary concerns of this program.

One of the major goals of the program is to reduce the cost of placing transmission lines underground. The underground transmission program is addressed to all the major cable technologies and to associate technologies, such as installation methods, maintenance, and forced cooling.

EPRI and ERDA closely cooperate on this program and jointly sponsor 15 of the 52 separate contracts that constitute this endeavor. *Program Manager: Ralph Samm*

Taped Cables

Research and development in taped cables is oriented toward higher voltage, higher ampacity, and more economical systems. Synthetic tapes, presently under development, should accomplish all these objectives. In addition, improved synthetic oils will complement synthetic tapes. Synthetic oils may also offer the benefit of being less resource dependent, since some can be manufactured from the by-products of the refining process.

In 10 years or less we expect taped cable systems will be uprated to 750 kv and above. These systems will have higher capacity, will be more efficient, more economical, and as reliable as present-day systems.

Extruded Cables

Extruded cables offer the best near-term solution for underground transmission at relatively small power levels, those rated 138–345 kv. Development and optimization of extruded cable systems could contribute to the conservation of natural resources because the energy and materials consumed in producing a typical second-generation extruded cable circuit are less than for a conventional HPOF circuit. All extruded cable projects are directed toward improving the reliability and lowering the cost of cables at the 230-kv and 345-kv levels. Sodium as a conductor is also being studied, not only to reduce cost and improve dielectric integrity but also to conserve the energy and resources required to fabricate conductor material.

Work on extruded cable joints and terminations for a complete system design is an important aspect of underground cable development. A premolded splice is being developed in one project for 138-kv extruded cable that includes a shielded cavity arrangement (RP7815). This will allow the use of compression or welded connectors and a heat transfer device to facilitate dissipation of heat developed in the joint. The design emphasizes speed of installation and reliability. In a second project, the design and manufacture of solid dielectric cables of increased quality is sought (RP7829). If these can be operated at higher dielectric stresses, the thickness of the insulation can be reduced. The development of terminations and splices particularly suited to a 138-kv cable design is included in this research.

Extruded cable systems are expected to be available in transmission voltages through 345-kv. Their reliability should approach that of taped cable systems, and their economy should be superior.

Gas Cables

The objective of the gas cable research is to develop gas-insulated cable systems that are capable of transmitting large blocks of power and are equivalent to overhead systems in the EHV and UHV ranges.

SF_6-insulated cables are the newest commercially available type of system to be accepted by the electric utilities. The major projects in this area are focused on developing a 345-kv flexible gas cable (sponsored by EPRI) and an 1100-kv rigid gas cable (sponsored by ERDA). Reliability and economy are emphasized in these projects.

In the flexible gas transmission project, we seek to reduce costs by substituting manufacturing technology for labor and by developing a less expensive enclosure made of aluminum strip rather than an extrusion. Innovative spacer designs and materials, along with new conductor designs and materials, will contribute to reduced cost and increased reliability.

Within the next 10 years flexible compressed-gas cable systems should be available at 345 kv and possibly above. More economic rigid gas cable systems will be attained by the three-in-one technology at 345 kv and above, and these may eventually incorporate flexible technology.

Projects are also underway to increase the operating temperatures of the systems via better materials and improved installation techniques (i.e., better backfill materials). This should be regarded as the goal for compressed-gas systems within five years or less. Beyond that period, our projects are designed to uprate the flexible system to higher voltages and to incorporate flexible technology into the three-in-one design concept.

The three-in-one compressed-gas system should offer a 10–15% reduction in cost over the rigid isolated-phase design. This system has been developed for 345-kv operation and will be offered for commercial use after all design parameters have been optimized. This technology also offers promise for operation at 500 kv and above.

Cryogenic Cable Systems

Cryogenic cable systems are being developed to accommodate the greater and more concentrated electric energy transportation requirements associated with urban growth and generation parks. Because of environmental restraints, lack of rights-of-way, and congestion of available underground routes, densification of capacity and energy transmission will become essential. Of course, reliability and economics will also be critical factors that the selected system must accommodate.

This subprogram area involves ongoing research on resistive cryogenic and superconducting systems, complemented by auxiliary hardware development and basic materials research. There are clear indications that scenarios for transmission cable requirements as described above are now being developed by several utilities.

DC Cables

The goal of the dc cable subprogram is to provide underground systems capable of carrying loads now projected for future systems and at voltage levels capable of interfacing with aerial dc transmission. The plan provides for cable, splices, and terminals at three voltage levels, ±400, ±600, and ±1200 kv. Prototype solid dielectric cables are presently being developed for ±100 kv. ERDA will be sponsoring the development of a ±600-kv taped-paper, oil-filled dc cable. In coordination with this effort, EPRI is committed to develop outdoor terminals and simplified splices for this cable system. In addition, a project to determine the maximum cable voltage rating obtainable with oil-cellulose insulation is now being considered.

Installation Methods

EPRI is concerned about the relatively small percentage of funds assigned to the study and improvement of installation methods. The R&D funding committed to the problem seems inadequate in view of the fact that the installation of the cable can account for up to 50% of the total installed cost. Significant contributions in this area are planned.

Innovative guided boring techniques, obstacle detection via ground radar, and water-jet cutting of concrete and paved surfaces are projects either underway or being considered for the near future.

A commercial design for a soil thermal resistivity and stability instrument has long been needed by the industry and will constitute a part of the proposed research. New drilling concepts and new welding techniques are also being proposed as part of EPRI's contribution to the near-term reduction of installation costs.

Cable Systems Maintenance

The cable systems maintenance subprogram is intended to improve fault location during both normal and abnormal day-to-day operations. Present research plans include development of equipment for improved and more accurate detection of cable faults and the detection of oil leaks in cable systems.

Forced Cooling

The goal of the forced cooling and cable ratings subprogram is to provide important near-term information and improvements that will lower the cost of underground transmission and reduce the total underground investment. Significant in this effort is a project on forced cooling being conducted at Waltz Mill, Pennsylvania (RP7823). Based on other existing and proposed projects, it has become evident that there will be a continuing need to use the forced cooling test facility at Waltz Mill. (Evaluation of different types of cable load management concepts is an example of one such need.)

Basic studies on the physics of forced cooling conducted at the university level will be extended. In addition to the basic physics of forced flow, the feasibility of electrohydrodynamic (EHD) pumping will be investigated. If commercially feasible, this technique will provide a pumping system with zero pressure differential from one end to the other. It is also believed that EHD pumps will lower the cost of pumping and thereby further contribute to the acceptance of forced-cooled systems.

High-capacity potheads or termination systems will be required for any high-capacity forced-cooled cable and will be pursued within this subprogram area. A proposed emergency chilling system consisting of a liquefied or chilled gas-to-oil cooler should offer an economic alternative for controlling or increasing the capacity of pipe-type cable systems during peak summer loads. This type of cooler would be intended for situations where only infrequent forced cooling would be required and where the expense of conventional forced cooling equipment could not be justified.

Test Facilities

The Waltz Mill underground cable test facility represents a significant portion of the underground transmission program budget. This facility has been used for the accelerated-life testing of both oil-impregnated paper and extruded dielectric insulation systems. In addition, extensive use is being made of the Waltz Mill facility to investigate thermal-mechanical problems and to analyze forced-cooled cable systems.

SUPERCONDUCTING GENERATORS

The design of generators using superconductors has been of interest for a number of years. Several advantages are offered by this concept: smaller size and weight, lower capital cost, greater stability, and potentially higher efficiency. The machine and its refrigeration components are easily transported—something not true of conventional generators. Much work has already been done by the Massachusetts Institute of Technology, initially sponsored by EEI and now by EPRI. Under RP672, MIT has built and tested a 3-Mva device. Certain key problem areas will now be addressed and hopefully resolved.

The central problem to be resolved is the design of an electromagnetic shield. The shield must insulate the superconducting part of the rotor from the influence of system current imbalances, changes in generator real and reactive loads, and disturbances (such as faults, local line switching, partial load rejections) and must continue to isolate the superconducting part of the rotor from the resultant armature magnetic field disturbances. The three basic shield design concepts that are now under investigation at MIT may lead to a definitive approach by the end of the contract period in September 1976.

Four other contracts have been authorized for design and/or construction of superconducting generators. One project (RP429-1) with General Electric Co. and one (RP429-2) with Westinghouse Corp. involve a detailed design of generators rated 300 Mva and a conceptual design at 1200 Mva. The work to date has shown that a 0.5% gain in generator efficiency can be realized. These contractors should benefit from MIT research by incorporating its findings into their design considerations for a commercial machine.

The third contract (RP563) is with Case Western Reserve University and involves the first stage of a development program to demonstrate the feasibility of a brushless flux-pumped superconducting field coil in a small prototype generator. The rather novel approach taken here is to excite the superconducting coils with a flux pump that is directly connected to the rotating coils. This one-year effort will demonstrate the feasibility of the concept by constructing a single-phase, 1-kva alternator with a rated open-circuit voltage of 50 kv.

The principal investigator at Case Western Reserve claims that this could lead to high-capacity superconducting generator designs that are smaller than similarly rated machines of conventional design. In addition, such a generator may have terminal voltages near or at system transmission voltage levels, as well as the ability to deenergize and recharge the coils rapidly by using a flux pump.

The fourth contract (RP798), with Battelle, Pacific Northwest Laboratories, involves the concept that any configuration of magnetic field may be stably stored with high fidelity to the original pattern field in a simple superconducting cylinder. This permits savings of space, weight, capital investment, and power wherever large magnetic fields are required, as in generators, MHD, and fusion. In generators, in addition to other advantages such as higher fields, the stored field has the potential of being deenergized more rapidly than any other field-producing method because there are no wires to melt or insulation to spark through during the high dI/dt.

The T&D Division Committee has recommended formation of a rotating machinery task force and program, which should become active in 1977. *Project Manager: Mario Rabinowitz*

At the Institute

EPRI BOARD APPROVES $55 MILLION IN NEW ENERGY RESEARCH

The Board of Directors authorized $55 million for 68 new research projects and increased authorizations for 32 active projects at its April 6 meeting.

A major authorization was $11 million for EPRI's share in a $45 million project to demonstrate first-generation fuel cell power plants. ERDA is providing the major portion of the funding, and United Technologies Corp. is also participating in the project. The demonstration, which is the next step in preparing these power generators for commercial use by the early 1980s, will be at a utility site to be selected shortly.

The construction and operation of a facility at Public Service Company of Colorado's Arapahoe Station to test new techniques for controlling the particulates resulting from coal combustion was another major authorization.

Also approved was an air quality monitoring project in the eastern U.S. to help determine the relationship between fossil fuel combustion emissions and regional air quality, as well as the relative importance of long-range pollutant dispersal. This project is part of EPRI's efforts to identify the origin of air pollutants, their potential biological effects, and the relationship of power plant emissions to regional air quality so that better control techniques can be developed.

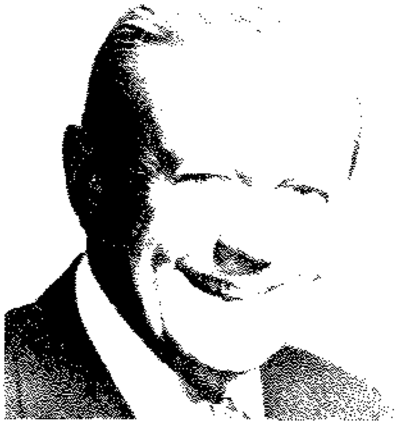
A number of nuclear power R&D projects to increase reactor reliability, operation, and performance were also approved.

Two major projects were authorized in electric power transmission and distribution research. One project involves the development of utility power poles from two waste products—scrap glass and fly ash. The "foamed glass" poles are expected to be less expensive than wood poles.

The second major transmission and distribution authorization was a project to demonstrate the feasibility of automated distribution-communication systems for the control of distribution equipment, load management, and time-of-day and automated metering.

Other Board actions resulted in the election of Robert I. Smith, president of Public Service Electric and Gas Co. of Newark, New Jersey, to the EPRI Board of Directors. He succeeds Robert F. Gilkeson, board chairman of Philadelphia Electric Co., who has completed his term on the EPRI Board.

Charlie F. Jack, chief engineer of Buckeye Power, Inc., Columbus, Ohio, was appointed to the EPRI Research Advisory Committee.



Smith

Jack

Pellet-Clad Interaction Subject of Workshop

The fuel for nearly all water-cooled commercial reactors consists of uranium oxide pellets clad in zirconium alloy tubes. Many conditions and circumstances can lead to cladding failure, including one effect called pellet-clad interaction. At a recent two-day EPRI-sponsored workshop on the subject, participants reviewed the status of projects that could lead to better control of this effect.

Pellet-clad interaction occurs when a fuel pellet expands during power changes and stresses the cladding tube. To avoid cladding failures, nuclear reactors are restricted in their rate of power change. The workshop addressed the key causes of pellet-clad interaction and how to prevent potential failures from such interactions.

According to Adrian Roberts, a program manager in the Nuclear Power Division's Systems and Materials Department, the major issue debated was whether the predominant cladding failure mechanism is purely mechanical in nature or is chemically assisted, that is, stress corrosion cracking. It is important to establish which mechanism controls pellet-clad interaction so that appropriate corrective action can be taken. While the workshop did not reach a conclusion on this issue, Roberts said that several experiments to achieve resolution were identified and will be included in ongoing EPRI projects. Roberts further stated that the phenomenon is an economic problem rather than a safety concern.

VEPCO Executive Joins EPRI

Charles L. Rudasill, Jr., joined EPRI's Planning Staff on June 1 to fill the newly created position of manager, Technical Assessment. Rudasill is on loan from Virginia Electric and Power Co. (VEPCO), where his career has spanned more than 25 years. Since 1968, he has served as VEPCO's director of transmission planning.

At EPRI, Rudasill will be in charge of Technical Assessment, which is part of the Program Plans and Technical Assessment Department. He will work closely with EPRI program managers to assist them in evaluating the potential payoffs from new and improved technologies that are being developed within R&D programs. Analyses performed by the Technical Assessment staff will provide EPRI with an enhanced understanding of how the technical performance characteristics and economics of new technologies can be optimized to meet the current and future system requirements of the electric utility industry.

Rudasill

"Typical utility system planning methods will be used in these reviews, and technological benefits will be examined for a number of hypothetical utility systems," said Dr. Walt Esselman, manager of the Program Plans and Technical Assessment Department. Esselman adds that Rudasill's many years of utility experience will help to ensure that his group uses analytic methods that are familiar to the utility industry.

Reporting Electrostatic Field Measurements

"There has been no consistent way of reporting electric field measurements in either the laboratory or the field," stated EPRI's Frank Young while explaining the background of a problem addressed at a recent two-day workshop sponsored by EPRI.

"In the past, measurements have been made and reported simply as 5 kv or 10 kv, without detailing such factors as the type of meter, the height level at which the measurements were taken, or the presence of nearby objects, such as steel beams, that could affect the measurements. These variables must be specified if different investigators are to accurately reproduce measurements."

EPRI transmission specialists feel that a standard reporting format is needed in order to compare EPRI projects involving electrostatic field strength measurements.

Fuel Rod Performance Reviewed

EPRI's fuel rod performance contractors and members of the Nuclear Power Division staff met in April to review individual projects and to comment on EPRI Special Report 25, *Planning Support Document for the EPRI Light Water Reactor Fuel Rod Performance Program.* The meeting was organized and cochaired by Adrian Roberts and Floyd Gelhaus, program managers in the Systems and Materials Department.

Although some of the projects have been active more than a year, Adrian Roberts stated that the meeting was significant in confirming EPRI's research plans for the next five years in this particular field.

"Up until the last six months we were mainly concerned with identifying research needs and formulating a program. The program has now been developed and most of the projects are underway," according to Roberts.

As stated in SR-25, the goals of the program are "to develop both the data base and the analytic tools that when applied to the design and irradiation of power reactor fuel rods will increase total plant availability by improving fuel rod reliability and plant operational flexibility."

The report further states that LWRs have been in large-scale commercial operation for over a decade, and during that time, changes in fuel rod design, materials, or process specifications have improved the reliability of fuel rods. However, there still remains a strong incentive to eliminate or to reduce the power rate-of-change limitation on fuel rods.

Roberts explained that the annual capacity factor effect as a result of fuel rod limitation has been as high as 5% in some plants, although it's generally lower. He feels that this program can help to reduce the limitation to a 1–2% effect on capacity factor, which would be worth several million dollars per year per plant in replacement power cost reduction.

Preventing POM Problems

Power plants are low on the list of polycyclic organic material (POM) sources, agreed the speakers at a recent EPRI–EEI seminar, "Polycyclic Organic Matter and the Utility Industry." They also concurred that there is a need for more information to ensure that these complex organic molecules do not become a problem in the future.

At the Chicago seminar, scientists from Battelle, Columbus Laboratories and EPA presented research findings on utility operations and POM emissions, new techniques for sampling and analysis, and the potential effects of these compounds on health.

POM levels in the U.S. have steadily declined in recent years. Alex Stankunas, a project manager in EPRI's Environmental Assessment Department, attributes the decline to more efficient combustion processes in industry, less heating of homes by coal, and the replacement of dump fires with landfills.

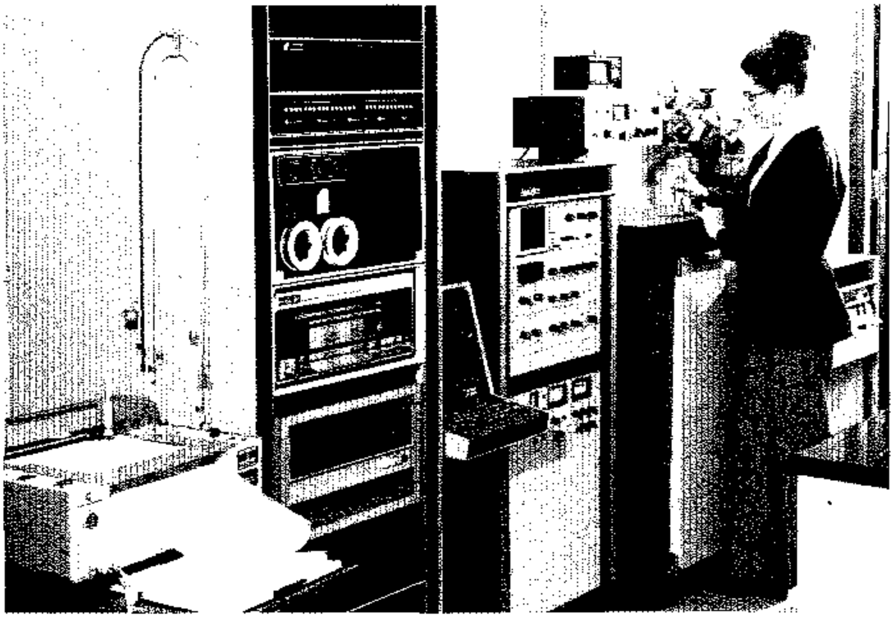
"Even though current utility emissions of POMs are low, both the Environmental Assessment Department and the Environmental Control and Combustion Program will continue to sponsor some POM studies, especially in the areas of sampling, analysis, and effects," said Stankunas.

In discussing the seminar and EPRI's interest in POM research, Stankunas outlined the two basic reasons for further studies. The first concerns technology being developed to meet stricter nitrogen oxide emission regulations. "We don't want to develop technology that decreases nitrogen oxide emissions at the expense of increasing POM emissions," stated the EPRI specialist.

The second reason for continuing studies relates to the commercial introduction of clean coal processes, such as coal liquefaction, coal gasification, and solvent refining, all of which have the potential for producing POMs, according to Stankunas. He added that further research will ensure that the process plants are properly designed to handle POM compounds.

"Our EPRI program on POMs is, in a sense, 'preventive medicine' so that these compounds will never become a problem that will require a crash correction program."

The analysis of POMs requires the latest in computer-interfaced instrumentation. A gas chromatograph—mass spectrometer—data processing system is used to test the efficiency of the adsorbent sampler developed by Battelle, Columbus Laboratories as part of EPRI's POM analysis efforts.



Fusion Meeting Planned

Plans for the second topical meeting on the technology of controlled nuclear fusion were recently announced by the meeting's sponsor, the American Nuclear Society. Cosponsors for the September 21–23 meeting to be held in Richland, Washington, are EPRI and ERDA.

The purpose of the meeting is to review and assess technological developments in controlled nuclear fusion since the first topical meeting in San Diego (April 1974).

Invited and contributed papers will address near-term reactor design, long-range reactor design, international fusion programs, materials, tritium and neutronics, magnetic and inertial confinement systems, plasma and blanket engineering, and environmental effects.

Guest speakers for the meeting will be Dr. Chauncey Starr, EPRI's president, and Congressman Mike McCormack of the state of Washington.

One of the main sessions of the meeting will review the national fusion technology programs of several countries, with reports from the United Kingdom, the Soviet Union, Japan, Germany, and Italy. William Gough will present EPRI's fusion program. These talks will help scientists assess the primary emphasis, funding level, and timetable of the technology programs in those countries with major fusion programs.

Further information can be obtained from R. G. Clark, Battelle, Pacific Northwest Laboratories, P.O. Box 999, Richland, Washington 99352, telephone: (509) 946-2529.

Workshop on Fusion Materials

Fusion power represents an important energy source for the future. However, commercial generation of electricity from fusion will require that reactors be reliable, maintainable, and environmentally acceptable. Which materials should we use to build reactors that meet these criteria?

When atoms fuse at very high temperatures, great amounts of energy are released, mostly as high-energy neutrons. Although no radioactive wastes are created in the fusion process itself, the high-energy neutrons strike the reactor materials and can "activate" them, or make them radioactive. The degree of activation depends on which materials—stainless steel, refractory metals, graphite, silicon carbide, aluminum—are used. Generally, the metals and alloys that are most suitable for use in constructing large, high-temperature devices become the most radioactive. Other materials, such as graphite, silicon carbide, and aluminum, have desirable low activation levels but present other kinds of structural limitations.

"Answering the materials question is one of the most challenging problems facing fusion developers today," said EPRI's Roger Richman, a materials support project manager. Materials support and fusion power staff members recently sponsored a workshop on this problem, which proved extremely valuable in helping to identify needed materials research. Although initial studies are underway in EPRI's fusion research, the workshop really marked the first direct attempt to assess the specific problem of reducing residual radioactivity of fusion reactors.

The two-day workshop in San Francisco was organized by one of EPRI's fusion contractors, McDonnell Douglas Astronautics Co. In attendance were representatives from utilities and architect-engineering firms, fusion physicists, materials scientists, manufacturers, and metals producers. The 30 specialists concurred on the need to begin a coordinated research effort on the activation problem.

According to Richman, "The general feeling was one of optimism that we will learn how to create and use materials for reliable and economic fusion reactors and through materials research and development, reduce radioactivity in fusion systems to a minor annoyance."

Fusion Plant Switches

"The switches required for fusion power plants should have a long life and low power loss and be able to operate at very high voltages and currents," said one of EPRI's fusion specialists, Noel Amherd, in discussing a recent three-day workshop he helped organize.

Amherd remarked that in some fusion reactor designs, switches would have to operate more than a million times each year. "With what we know today, it's technically possible to switch power this many times, but at much lower voltages and currents than will be used in fusion plants," said Amherd.

"The switching requirements for fusion reactors originate in two areas: internal power conditioning and the connection of the power plant to the utility system," the EPRI project manager explained. He further said that only the first area is sufficiently defined today to allow a listing of the requirements, although it is expected that developments in one area will help in the other.

"Whether the fusion concept is that of tokamaks or mirrors for magnetic plasma confinement or laser-fusion for inertial confinement, large amounts of power must be controlled for initiating and possibly sustaining the burning of the fusion fuel."

How would switching be applied in such pulsed systems as laser-fusion? Amherd said that in this type of system a laser beam impacts a fuel pellet to release energy. "Each time the beam impacts the pellet, the laser has to be recharged through an operation that requires switching of electric power," he stated, pointing out that the switching equipment would have to be used thousands of times each day. "Developing a reliable switching unit that could operate satisfactorily under these very high voltages and currents would require a concentrated research effort."

All types of fusion plants were considered at the workshop, from experimental power reactors to commercial units for both magnetic and inertial confinement fusion. Besides EPRI staff, specialists from universities, industry, electric utilities, and government research laboratories attended the workshop.

"It was a broadly based group of specialists," said Amherd, "who recommended an extensive research effort that even includes consideration of whether fusion systems could be designed without switches."

NAE Honors Engineers

One EPRI director and three members of the Advisory Council were among the 104 American engineers recently elected to membership in the National Academy of Engineers (NAE).

Election to the academy is the highest professional distinction that can be conferred on an engineer. It is an honor given those who have made important contributions to engineering theory and practice or who have demonstrated unusual accomplishments in new and developing technologies.

Milton Levenson, director of EPRI's Nuclear Power Division, was honored for "contributions to fast reactor technology, nuclear fuel reprocessing, and especially the first remote-handling, completely closed-fuel-cycle plant."

The Council members honored were:

Ruth M. Davis, director, Institute for Computer Sciences and Technology, National Bureau of Standards, for "contributions to computer sciences, particularly information science technology."

Arthur G. Hansen, president, Purdue University, for "pioneering work in flow phenomena in turbomachine blade row and ducts and contributions to engineering education."

Arthur C. Stern, professor, Department of Environmental Sciences and Engineering, University of North Carolina, for "pioneering technological development for assessing air pollution, nationally and internationally."

Symposium on Fault Current Limiters and Power Circuit Breakers

Industry attention is being directed to developing fault current limiters and improving power circuit breaker interrupters through R&D programs at EPRI, ERDA, and other organizations. Many of these projects have begun to provide important findings, and EPRI's Transmission and Distribution Division is sponsoring a symposium September 28–30 at the State University of New York, Buffalo, to review these data.

In announcing the symposium, John Dougherty, director of the Transmission and Distribution Division, said that investigators who are working on the utility system application of fault current limiters, interrupter developments, and arc physics will be invited to submit papers.

The symposium agenda will be equally divided between papers and open discussions among the participating researchers, designers, application engineers, and utility operations personnel.

Those interested in receiving more information or a registration form are invited to contact Richard Kennon or Glenn Bates, Transmission and Distribution Division, EPRI.

Problem Boilers?

Two EPRI program managers in the Fossil Fuel and Advanced Systems Division need information on boilers, 300 Mw or larger, that have been derated. If you can help, please write or call either Shelton Ehrlich or Don Anson at EPRI, (415) 493-4800, and give the location and size of the unit(s).

Changes in Power Mix

How will our generation mix change over the next 25–50 years and beyond?

- Coal will probably share 40–50% of the electric utility marketplace through the next 75 years and will then be phased out over a period of 25–30 years.
- First-generation light water reactors (LWRs) will increase dramatically, accounting for 30–40% of the generation capacity by the year 2000, and then will be supplemented by the liquid metal fast breeder reactors (LMFBRs). Such systems have the capacity to recycle uranium and plutonium and hence supply a renewable energy source for centuries.
- Oil-fired capacity will increase in the 1980s but will be reduced essentially to zero by the year 2000, with the exception of those plants burning coal-derived liquids. Oil-fired-equivalent plants will be fueled from biomass-derived fuels.
- Advanced geothermal and solar power plants will begin to impact the generation mix in the 1990s.
- The breeder reactors will be introduced in the 1990s and together with solar must assume a major share of the burden of system expansion in the post-2000 time period. They will play the dominant generation role in the year 2050, with fusion power increasing its role beyond this period.

These projections were presented by EPRI's Dwain F. Spencer at the annual conference of the Engineering and Operation Division of the Southwestern Electric Exchange held in New Orleans in late April.

Spencer, who is director of the Advanced Fossil Power Systems Department, said that these projections are based on his recent assessment of resources needed to meet potential future electric consumption rates and a review of the status of conversion alternatives.

"We anticipate that our generation spectrum over the next 100 years will shift from the present fossil base, quickly pass through the first-generation nuclear power plants and geothermal potential, and settle on the breeder, solar, biomass, and fusion systems," Spencer said.

"Clearly, the use of coal will remain a mainstay to electric power generation over the next 50 years and probably until supply shortages preclude its continued use. Although direct combustion of pulverized coal appears to be the most economical choice for baseload power, including even wet scrubbing to remove sulfur, we envisage an increased use of synthetic fuels from coal."

Spencer outlined six major alternatives being considered for electric utility use of coal: pulverized coal-fired boilers, fluidized-bed combustion, low- and intermediate-Btu gasification, coal preparation that includes chemical treatment, clean liquid fuels production, and multistage combustion coupled with magnetohydrodynamic combined cycles.

Regarding nuclear fission, Spencer stated that nearly all projections of increased electric generating capacity predict a rapid increase in LWR nuclear plants.

"Most of the ERDA projections lead to an installed nuclear capacity of approximately 600,000 Mwe by the year 2000, with an annual electricity production capacity of 3500 billion kwh," he remarked.

"This level of LWR capacity would tax the availability of economic uranium supplies. However, the availability of LMFBRs would enable the United States to use its existing uranium resources for centuries to come; hence, the importance of the breeder reactor program.

"With this limiting factor facing us," he added, "it's obvious that the breeder reactor program must be advanced as rapidly as possible."

He concluded his presentation by commenting that within 50–75 years the U.S. must develop the capability of using only renewable energy resources, such as the LMFBR and solar energy, to meet even a 5% annual growth rate in electricity demand.

Project Highlights

Attitude Survey on Peak Load Pricing

What relationship do people see between the energy shortage and their own consumption of electricity? What do they know about the cost of producing electricity? How and why would they respond to peak load pricing?

Answers to these types of questions will be sought by a San Francisco market research firm as part of a nationwide study on electricity rate design being sponsored by EPRI and the Edison Electric Institute (EEI).

The one-year, $1 million effort was requested by the National Association of Regulatory Utility Commissioners (NARUC) to determine appropriate rate structures in light of escalating energy costs.

Elrick & Lavidge, Inc., the firm chosen to query consumers on peak load pricing, will interview residential, commercial, and industrial users who are presently being billed under conventional rate structures in four regions of the U.S.

In announcing the new contract, Robert G. Uhler, executive director of the Electric Utility Rate Design Study, said that Elrick & Lavidge, Inc., will also be working closely with state agencies and the Federal Energy Administration to explore the attitudes and behavior of electricity customers who are paying peak load prices in several load-management demonstration projects.

The firm's work will be closely coordinated with that of a customer acceptance task force of utility marketing and rate managers, as well as regulatory experts, which has been established for the rate design study.

"Customer attitudes and technical considerations are equally important in the question of peak load pricing," said Uhler. "Thus, while Elrick & Lavidge will concentrate their efforts on customer attitudes, the task force will be examining economic and engineering constraints to peak load pricing."

Elrick & Lavidge will submit their preliminary report this summer. The rate design study project committee will evaluate the research and make a report to NARUC by early fall.

Fuel Cell Development

Development of a utility fuel cell, a device that produces electricity by an electrochemical rather than a thermal process, continues through a $7.2 million contract recently awarded to the Power Systems Division of United Technologies Corp.

Prior research at United Technologies under EPRI sponsorship confirmed the technical feasibility and potential cost benefits of advanced fuel cell concepts employing either molten carbonate or phosphoric acid electrolytes. In the new three-year project, researchers will attempt to develop the technology and designs for these experimental generators so that they will have a 40,000-hour life and a 45% efficiency while operating on utility fuels, such as low-sulfur distillate oil.

Researchers will also be working to identify the more promising of the two electrolyte concepts in anticipation of a pilot plant demonstration planned for late 1979.

"The molten carbonate and advanced phosphoric acid concepts represent second-generation fuel cell power plants," said Arnold Fickett, manager of fuel cell studies, "If their development proceeds on schedule, they should offer improvements in efficiency, capital cost, and operation over the first-generation fuel cell power plants, which are expected to be in service in the U.S. by the early 1980s."

Fuel cells convert the chemical energy of a fuel directly to dc electricity without an intermediate combustion process. Because there is no combustion, there is no ash to dispose of or pollutants to control.

"Devices like batteries and fuel cells involve electrochemical rather than thermal processes, so they can achieve higher energy efficiencies than conventional generators. The Carnot cycle limitation is not imposed," stated Fickett, citing the fact that fuel cells offer the potential of a 40–50% efficiency rating compared with the existing range of 33–38% for steam turbines.

Predicting Steam Turbine Rotor Lifetime

A two-year, $1.3 million research project was recently initiated to improve power plant reliability by probabilistic predictions of steam turbine rotor lifetime.

An improved steam turbine lifetime analysis system in conjunction with better turbine rotor inspection capability will help plant engineers in making removal-for-cause decisions and in planning inspection outages, according to Floyd Gelhaus, a program manager in the Nuclear Power Division.

The overall program involves three contracting firms that will perform four separate tasks related to the reliability of steam turbine rotors.

Under Task 1, Southwest Research Institute, San Antonio, Texas, will develop and verify a computerized lifetime predictive analysis system for steam turbine rotors.

Under Task 2, Battelle, Columbus Laboratories will conduct a series of nondestructive inspection tests on retired turbine rotors and flawed specimens. The objective is to improve the industry's inservice examinations for detecting and analyzing turbine rotor flaws, as well as to provide the Task 1 contractor with inspection data input for the lifetime calculations.

Westinghouse Electric Corp. Research and Development Center will perform Task 3 and Task 4. Both tasks involve destructive testing to characterize the true nature of the rotor defects identified by the Task 2 nondestructive evaluation methods and the fracture properties and materials responses to service loading conditions for specimens representative of steam turbine rotors.

EPRI Negotiates 32 Contracts

Number	Title	Duration	Funding ($000)	Contractor
Fossil Fuel and Advanced Systems Division				
RP361-2	Upgrading of Coal Liquids for Use as Power Generation Fuels	2 years	457.3	Mobil Research and Development Corp.
RP538-1	Preparation of a Data Book on High Temperature Oxidation and Corrosion of Metals and Alloys	15 months	18.0	Battelle, Columbus Laboratories
RP632-2	Advanced Electrostatic Precipitator Pilot Plant	6 weeks	125.1	Combustion Engineering, Inc.
RP717-1	Fluidized-Bed Combustion Retrofit Study-Consulting Services for Step 2	6 months	12.2	Combustion Processes, Inc.
RP736-1	Influence of Mineral Matter of Coal on Fireside Slagging and Fouling of Utility Boilers	6 months	306.8	Battelle, Columbus Laboratories
RP774-1	Particle Association Mechanisms in Coal-derived Liquids	1 year	68.0	West Virginia University
RP777-1	Design Fabrication and Evaluation of Coal Liquefaction Letdown Valves	9 months	70.0	Consolidated Controls Corp.
RP779-1	Gas Extraction of a Western Subbituminous Coal	5 months	12.7	Catalytica Associates, Inc.
RP779-2	Viscous Properties of Coal-SRC Mixtures	3 months	7.3	Battelle Memorial Institute
RP780-1	Fine Particulate Trace Element and Engineering Evaluation of Electrostatic Precipitators	1 year	250.0	Meteorology Research, Inc.
RP781-2	Comparison of Fine Particulate Measurement Techniques for Source Testing in the Utility Industry	9 months	30.1	Meteorology Research, Inc.
Nuclear Power Division				
RP230-3	Decay Heat Program	6 months	25.0	General Electric Co.
RP494-1	Single- and Multiparameter Lowdown Heat Transfer Tests	10 months	833.8	Westinghouse Electric Corp.
RP621-1	Optimization of Metallurgical Variables to Improve the Stress Corrosion Resistance of Inconel 600	30 months	235.9	Westinghouse Electric Corp.
RP684-1	Transient Modeling of Steam Generator Units in Nuclear Power Plants	2 years	140.0	University of Michigan
RP686-1	Defining Document for a Design/Evaluation Model for BWR Power Plants	8 months	34.5	Philadelphia Electric Co.

Uranium Detection

Current techniques for detecting uranium ore deposits, exclusive of actual drilling, can sample only surface and near-surface areas. Cost-effective methods for locating deeply buried deposits of uranium have not yet been developed, although a new study being sponsored by EPRI may help to advance this technology.

The study is investigating the potential of helium as a guide to uranium ore deposits and is being performed by Martin Marietta Corp. with the close cooperation of ERDA and other research groups.

"Anomalous concentrations of helium produced during the radioactive decay of uranium are likely to be associated with uranium deposits, at least in theory," according to the EPRI manager for the study, Jeremy Platt, who further commented that if the technique proves successful, the economics of locating hard-to-find deposits should improve because fewer drill holes would be required.

Helium and other possible uranium indicators, including radon, will be measured in the vicinity of known uranium ore bodies as part of the one-year study.

EPRI officials have reported that coal and uranium are going to be America's chief electric energy resources for the remainder of the century, pending the commercial development of new energy technologies.

According to Platt, a staff member in the Energy Supply Program, most of the U.S. surface uranium deposits probably have already been detected. "If this proves to be true, the results of the helium study and related efforts by ERDA, the U.S. Geological Survey, and others become even more critical."

Number	Title	Duration	Funding ($000)	Contractor
RP687-1	Thermohydraulic Forces Associated with Crack Propagation in Reactor Piping	18 months	72.6	University of Kentucky
RP698-1	Evaluation of Electromagnetic Acoustic Concepts for Inspection of Steam Generator Tubing	1 year	74.4	Rockwell International Corp.
RP700-1	Failure Analysis and Failure Prevention in Electric Systems	1 year	500.0	Failure Analysis Associates
RP706-1	BWR Oxygen Control Demonstration Program	13 months	95.3	Nuclear Water and Waste Technology, Inc.
RP710-1	Development of an Improved Reactor Core Simulator for Fuel Cycle and Operations Analysis	1 year	129.4	Yankee Atomic Electric Co.
Transmission and Distribution Division				
RP745-1	Development of Short- and Mid-term Simulation Techniques for Large Interconnected Electric Power Systems	21 months	340.9	Arizona State University
RP748-1	Combustible Gas-in-Oil Detector	19 months	172.5	Westinghouse Electric Corp.
RP795-1	Surge Behavior of URD Cable Systems	21 months	257.6	McGraw-Edison Co.
RP797-1	Ground Potential Due to Loss of Cable Neutral—Computer Program	11 months	70.7	Georgia Institute of Technology
RP7851-1	A New Class of Solid Additives to Inhibit Tree Growth in Solid Extruded Cable Insulation	14 months	115.0	General Electric Co.
RP7854-1	Improved 138/230-kv Rated Solid Dielectric Transmission Cable System	3 years	798.0	Phelps Dodge Cable and Wire Co.
Energy Systems, Environment, and Conservation Division				
RP434-8	Electric Utility Rate Design Study	7 months	34.9	Gordian Associates, Inc.
RP434-9	Electric Utility Rate Design Study	7 months	35.0	Systems Control, Inc.
RP755-2	Methodology for Estimating Air Pollution Damage from Coal-Burning Power Plants	1 year	75.5	University of Wyoming
RP807-1	Potential of Helium as a Guide to Uranium Ore	13 months	139.8	Martin Marietta Corp.
RP809-1	Research Needs on the Health Effect of Fossil Fuel Combustion Products	2 years	150.0	National Academy of Sciences

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

EPRI SR-34 NUCLEAR POWER, COAL, AND ENERGY CONSERVATION
Special Report

The options most likely to relieve U.S. dependence on the world's limited supplies of oil and gas over the next 20 to 40 years appear to be nuclear power, coal, and energy conservation. This analysis is concerned primarily with two secondary forms of energy—electric and nonelectric (i.e., liquids and gases). Coal can supply both the electric and nonelectric sectors either by direct combustion or by conversion to synthetic fuels. Nuclear fuels may be used to generate electricity and also to produce hydrogen by electrolysis to supply the needs of the nonelectric sector. Consequently, there are paths in the model by which either coal or nuclear fuels can meet all energy demands, with the proportions of their contributions being determined by the relative costs of fuel substitution.

The prospective benefits of the breeder reactor and of synthetic fuels are examined within this framework. The model shows that reductions in energy demand are price-induced, although it is also designed to incorporate mandatory conservation measures. Furthermore, the model allows for the appearance of an advanced technology (whether based on solar, fusion, or an advanced nuclear breeder) some 20 years after the commercial introduction of first-generation breeders.

Energy Systems, Environment, and Conservation

EPRI EC-125 DESIGN OF THE SULFATE REGIONAL EXPERIMENT (SURE)
Final Report

The impact of gas and particulate emissions from power plants on regional air quality must be assessed because of the apparent correlation of these pollutants with observed health and ecological effects. Also at issue are second-generation pollutants, such as sulfates, nitrates, and acid precipitation. To better understand the transport, conversion, and fate of such agents under various meteorological conditions, EPRI plans a major regional air quality monitoring program in the eastern states.

To provide supporting information for this effort, Environmental Research & Technology, Inc. (ERT) conducted a planning study for EPRI's research program (RP485), entitled *Design of the Sulfate Regional Experiment (SURE)*. The results of this study are presented in a four-volume report: Volume I, Supporting Data and Analysis; Volume II, Proposed Experimental Design; Volume III, Appendixes; and Volume IV, Executive Summary. The executive summary (Volume IV) presents the data and reviews the analytic procedures that support the design of SURE.

The purpose of SURE is to develop an understanding of the correlation between sulfur oxide emissions and ambient air quality. To this end, ERT prepared and examined a new annual set of simultaneous SO_2 and water-soluble sulfate air quality data collected in the Ohio Valley during 1974 and 1975. Results have been compared with recent data from U.S. government archives. Several tentative conclusions have emerged: significant differences in sulfate behavior seem to occur in different geographic regions; the widespread summer maximum in sulfate concentrations observed in the northeast does not occur elsewhere; the highest annual sulfate levels are observed in the region of West Virginia and western Pennsylvania; a systematic correlation is observed between high sulfate levels and the temperature, the atmospheric water vapor content, and the tropical airflow; and the highest intensity of sulfate appears to be confined to regions less than a few hundred kilometers downwind from isolated sources of SO_2.

These conclusions suggest that the high sulfate levels experienced in the northeast result from the location of many large SO_2 sources in the path of warm air masses, as well as from slow atmospheric oxidation processes. *Environmental Research & Technology, Inc.*

EPRI 571-1A HEALTH EFFECTS OF NITROGEN OXIDES
Quarterly Report

This is the second in a series of topical reports detailing the health impact of selected fossil fuel pollutants, based on available toxicological and clinical research data. The first report dealt with selenium and its compounds, and the next two reports will cover mercury and oxides of sulfur, respectively.

Levels of nitrogen dioxide and ozone often exceed national and state ambient air quality standards in many urban locales. Although the evidence is not conclusive, it strongly suggests that nitrogen oxides are measurably detrimental to public health in highly polluted areas. In some areas NO_2 presents a possible direct health hazard, while in others the ozone levels caused in part by NO_2 are of more concern. Therefore, NO_2 regulations may be imposed for various reasons and/or different objectives. Toxicological experiments on laboratory animals have not demonstrated deleterious effects below a 0.4 ppm NO_2 exposure level. It would not be prudent to expect a threshold for human health effects to exist at some similar level in view of (1) the range of general human health that exists, especially among the highly susceptible segments of the population, such as the elderly, the infirm, and the young; (2) the paucity of long-term, low-level experimental data on animals; and (3) the many uncertainties in extrapolating from animal data.

This report describes the oxides of nitrogen associated with fossil-fuel-fired power plants and their chemical kinetics. It primarily covers the health effects that have been observed in humans and the various toxicological studies that have been conducted. The resulting implications and a set of recommendations form the conclusion. *Science Applications, Inc.*

Fossil Fuel and Advanced Systems

EPRI 265-2 LOW-BTU GAS STUDY
Final Report
This report presents an analysis of the performance of four utility boilers burning five specific low- to medium-Btu gasified coal fuels. The boilers studied were all originally designed for different fuels and are of varying sizes and configurations.

Each unit was investigated in order (1) to determine the performance of an as-built boiler when firing each of the five specified gasified coal fuels and (2) to ascertain what practical physical changes could be made to each unit to permit operation at or near rated capacity and steam temperatures.

The performance criteria on the four units are tabulated and discussed in separate sections, each with the same basic format: summary and conclusions; original design; calculation procedure; unit performance on low-Btu fuel; discussion of results; figures, tables, and summary sheets.

Among the more significant findings of this investigation is the fact that the units studied can use the higher-Btu fuels ($\geq$ 300 Btu/scf) in most cases with relatively few changes. However, use of the lowest-Btu fuels in certain types of boilers may necessitate modifications so extensive as to be impractical. *Babcock & Wilcox Co.*

EPRI 415 NEW CATALYTIC MATERIALS FOR THE LIQUEFACTION OF COAL
Final Report
To meet future demands for clean-burning liquid fuels, economic processes for coal liquefaction must be developed. In view of time constraints, first-generation coal liquefaction processes are likely to be based on existing catalyst technology (largely an outgrowth of petroleum processes), which may cause problems when applied to coal liquefaction. To surmount these difficulties, second-generation processes will require improved catalytic materials and concepts. These improvements will come from developments in catalysis and advances in relevant disciplines, such as inorganic chemistry and solid state and materials science.

This study provides a perspective for potential second-generation catalytic materials for the direct liquefaction of coal to boiler fuel. Both fundamental aspects and engineering constraints were considered in evaluating materials and assigning a priority for further study.

A detailed analysis of broad classes of materials ranked them in terms of their potential as catalysts for the direct liquefaction of coal to boiler fuel. In general, however, there were sufficient physicochemical data to determine the behavior of these materials in a coal liquefaction environment. By far the greatest discerning factors were thermal and chemical stability. In addition to physicochemical properties, engineering criteria, such as catalyst separation, handling, and cost, as well as heat and mass transfer phenomena, were considered where possible. *Catalytica Associates, Inc.*

Nuclear Power

EPRI 96-3 DIAGNOSTIC STUDIES OF TURBULENT HEATING IN THE TEXAS TURBULENT TORUS AND THE RELEVANCE OF TURBULENT HEATING TO FUSION EXPERIMENTS AND REACTORS
Final Report
This project continued EEI-supported work on the Texas Tokamak and completed the data acquisition system begun under RP96-2.

The Texas Tokamak experiment aimed at combining the heating potential of turbulence with the tokamak magnetic confinement system. It was designed as the logical extension of previous small turbulent heating experiments set up to explore the process in a device with the size and confinement needed for fusion studies. The original hope for the Texas Tokamak was twofold: (1) to achieve electron temperatures in the range of 10 kev during a turbulent heating pulse lasting approximately one microsecond; and (2) to effect the transition from the turbulent heating phase to the confinement phase without violent disruption of the plasma. *The University of Texas*

EPRI NP-101 RADIOIODINE SOURCE AND OTHER RADIONUCLIDE EFFLUENT MEASUREMENTS AT NUCLEAR POWER PLANTS
Progress Report
Comprehensive measurements are being undertaken within three boiling water reactors (BWRs) and four pressurized water reactors (PWRs) to collect radioiodine and other radionuclide data as part of a research project to develop information and test models on emission sources and transport mechanisms. This report contains data accumulated from the three BWRs during the period April—August 1975. Measurements from all seven reactors will be completed early in 1977.

This project is expected to produce experimental data that will permit greater accuracy in predicting the fate of radioactive materials within nuclear power plants. The results should help improve plant design and facilitate licensing by alleviating present conservative assumptions necessitated by lack of operating data. *Science Applications, Inc.*

EPRI NP-114 PRESENT STATUS OF ECC COMBINED INJECTION: A LITERATURE SURVEY
Topical Report
This report describes the completed first phase of the combined injection emergency core cooling (ECC) project, jointly funded by EPRI and the State University of New York at Buffalo. The project is designed to investigate the combined top-and-bottom injection ECC and reflood phenomena that occur in a scaled pressurized water reactor (PWR) configuration after a hypothetical loss-of-coolant accident (LOCA). It is expected that the potential usefulness of combined top-and-bottom injection toward improving the performance of current light water reactor emergency core cooling systems (LWR–ECCS) will be examined and confirmed.

In this survey, the general background of ECCS as employed in PWRs is reviewed briefly and is followed by a summary of publicly available literature relative to combined injection ECC. Since the fundamental mechanisms, and hence the analytic modeling, of top, bottom, and combined injection are basically similar, several single-injection models are summarized in the final section of the report. *State University of New York at Buffalo*

EPRI NP-118 EXPERIMENTAL METHODS IN TWO-PHASE FLOW STUDIES
Final Report
This survey of experimental methods and instrumentation in two-phase flow represents the first part of a contract being carried out for EPRI by the Heat Transfer and Fluid Flow Service (HTFS), Harwell, England.

The methods are reviewed under first-order parameters (those of direct interest to the designer), second-order parameters (time-averaged values), and third-order parameters (time-varying quantities). The first-order parameters are divided into primary design parameters applying both to the steady state (e.g., pressure drop, maximum heat flux) and to fault conditions (e.g., discharge rate, void growth), and into secondary design parameters, such as vibration and flow distribution. Second-order parameters include flow pattern, mass-flow distribution, drop-size measurement, and temperature distribution and are not generally used in the design of the system. However, both they and the time-varying parameters (third order) may be of vital importance in establishing new methods for evaluation and understanding of design parameters. In conclusion, the report deals briefly with modeling of two-phase systems and improvement of their performance. *Atomic Energy Research Establishment*

EPRI 289-2 SINGLE-TUBE TEST FACILITY DESCRIPTION FOR PWR BLOWDOWN HEAT TRANSFER PROJECT
Technical Report 1
A major concern in the design of power reactors is that sufficient cooling capability be provided to keep fuel element clad temperatures below specified values, even for a postulated break in principal coolant loop components, such as the main recirculation loop pipe. Therefore, it is necessary to be able to predict system performance in such a loss-of-coolant accident (LOCA) and to evaluate accident-preventing and/or mitigating steps in the design of the system. As part of the continuing effort for improving and advancing safety technology, the CE–EPRI blowdown heat transfer (BDHT) project is designed to provide basic data on the reactor core thermal-hydraulic performance under hypothetical LOCA conditions.

A single-tube test facility will be used in undertaking BDHT studies for parametric boundary conditions, which are closely representative of the major hypothetical PWR/LOCA (the large, double-ended cold leg break).

The background and objectives of the program are described, as well as test apparatus components and their performance. Measurement systems and data acquisition equipment are discussed briefly, leaving detailed description to a later instrumentation report. The report concludes with the operating procedures for approaching and establishing the initial test conditions, together with the blowdown test performance. *Combustion Engineering, Inc.*

EPRI 289-2A ROD BUNDLE TEST FACILITY DESCRIPTION FOR PWR BLOWDOWN HEAT TRANSFER PROJECT
Technical Report 2
This report describes the rod bundle blowdown heat transfer facility used to simulate PWR core conditions during early stages of a hypothetical loss-of-coolant accident (LOCA). The facility is located at the Columbia University Heat Transfer Facilities in New York City. This text outlines and defines the physical systems that constitute the facility, as well as the specific test sections to be used during experimentation. Measurement and data acquisition systems are also described. *Combustion Engineering, Inc.*

EPRI 472-1 MAJOR FEATURES OF D–T TOKAMAK FUSION REACTOR SYSTEMS
Interim Report
During the past four years the field of fusion reactor design has been very active. In order to gain some perspective on the trends in this field, the parameters of various proposed designs require a detailed comparison. The object of this report is to present such a comparison, with respect not only to the traditional plasma parameters but also to those of blankets, shields, coolants, tritium, neutronics, materials, magnets, power cycle, resources, and economics.

This report comprises tables that compare various designs of fusion-fission reactors based on the tokamak configuration. The reactors (four near-term, five mid-term, and ten long-term) range from present experimental devices to conceptual commercial units.

However, since reactor designs are constantly in a state of flux, the information presented was valid only at its time of collection. Nevertheless, there is value in freezing the design parameters at a given instant in time so that the entire technical community from the plasma physicist to the electric utility engineer can view developments with respect to operating parameters. *McDonnell Douglas Astronautics Co.—East*

Transmission and Distribution

EPRI SR-35 OVERHEAD TRANSMISSION CONSTRUCTION AND MAINTENANCE SEMINAR
Summary Report
In January 1976, the T&D staff of EPRI sponsored a seminar to study the construction and maintenance problems of transmission facilities that EPRI might consider for future projects and programs.

It was felt that EPRI could benefit from the insights and experience of the transmission industry. Consequently, EPRI invited to the seminar experts in the fields of transmission design, construction, and maintenance; conductors, insulators, steel, suspension hardware, construction tools, and construction heavy equipment; and clearing and maintenance of transmission rights-of-way. Also invited were representatives from consulting firms engaged in design work on transmission and design personnel from various utilities.

The report contains summaries written by the chairmen of the five seminar groups: towers and footings, maintenance, wire stringing, right-of-way and clearing, and design as it affects construction and maintenance.

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June 1976