Energy Keystone

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Cover: The familiar lump of coal stands for energy in a way that no oil barrel, gas pipeline, or nuclear fuel rod ever could. Now that we need it again, how big is this lump? How expeditiously will we be able to get at it?

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Coal Quandary

At a time when we are striving to make greater use of domestic energy resources, nearly all experts point to coal as one of the few short-term alternatives with significant potential for electric power production. Projections tell us that coal use in the year 2000 will be over 35 quadrillion Btu and that at least two-thirds will probably be consumed by the electric power industry.

Although most generation plants at that time will probably still be directly firing pulverized coal, a broad array of new technologies are being developed and readied to use coal both efficiently and in a more assuredly "clean" manner. These include: chemical coal cleaning (such as solvent-refined coal), coal hydrogenation (to produce liquid fuel from coal), fluidized-bed combustion (to capture sulfur ahead of the exhaust stack), and coal gasification integrated with combined cycles (converting coal to a low- or intermediate-Btu gas and then extracting its energy through gas and steam turbines in tandem). In addition, new systems are being developed to transport coal from mine to power plants. Each of these technologies offers different performance and economic incentives; however, all depend on having coal available.

Encouragingly, in this circumstance, we have long thought that the United States has a nearly inexhaustible supply of coal; even, some experts say, for 300 years

or more. But in this month's lead article, we look beyond this apparent panacea to consider just what our usable coal inventory may be. Further, we begin to assess the real question, "Can enough coal be produced to meet our potential demand?"

As we will see, there appear to be shortfalls developing in eastern coal output, even within the next 10 to 15 years, and western coal production remains a question mark due to the heavy influence of federal government holdings and policies. Tightening environmental restrictions based on use of the "best available control technology" may force the use of precombustion coal beneficiation as well as postcombustion control of sulfur oxide, nitrogen oxide, and particulate emissions from coal-fired plants, even from those burning low-sulfur coal. Against the seemingly endless set of requirements and restrictions, can coal really play the role in which it is cast?

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

▪ In an apt phrase from the National Coal Association, "coal is the ace in the hole." The inference is that fuels are the high cards in the resources poker game of this energy-intensive nation. The players are producers and users, policymakers and economists, regulators and geologists, electric utilities and technologists. It is a long-standing game of high stakes, heavy betting, and inevitably some bluffing, played against a background of kibitzers.

Which player holds the ace? Who determines its true value? How?

Coal's value is more than a matter of tonnage figures or regional pricing or even mineral constituents. It is influenced by a complex mix of definitions, long-standing perceptions, and practices among many industries that pervade the U.S. economy and require the talents of all the players in the resources game. Some insights are offered in this month's cover feature, **"Coal: Keystone of Energy Fuels"** (page 6).

Richard A. Schmidt writes with the perspective of an economic geologist and the sentiment of one who has heard the creakings of a coal mine roof deep underground. A project manager in EPRI's Advanced Fossil Power Systems Department since early 1974, he previously spent more than six years with SRI International (formerly Stanford Research Institute) in energy resource development and management, specializing in coal in the U.S. and abroad. Trained as a geologist at Franklin and Marshall College (BS 1957) and the University of Wisconsin (MS 1959, PhD 1963), Schmidt has participated in assessments of the mineral resource potentials of Alaska and Saudi Arabia and has contributed to studies sponsored by federal and state agencies on energy and environmental topics.

▪ In **"Load Forecasting—Modeling With Judgment"** (page 12), **Anthony Lawrence** acknowledges that advances in computerized data manipulation have led to improved forecasting methods. But his point remains that "the forecaster's good judgment always has been and always will be the sine qua non of load forecasting."

Lawrence is a project manager in the Demand and Conservation Program of EPRI's Energy Analysis and Environment Division. He is responsible for studies in the development of load-forecasting methods and is also involved with research into energy use for transportation and commerce. Last spring Lawrence participated in an international load-forecasting conference in England, which was attended by leading time-series statistical economists and economic analysts from energy and communications industries. He also took part in a load-forecasting workshop in Aspen, Colorado, together with academic, government, and industrial economists from throughout North America.

Lawrence came to EPRI in 1975 from the University of Kentucky, where he was an assistant professor of economics. From 1972 to 1974 he served as a research economist with the U.S. Bureau of Labor Statistics in the Office of Prices. Earlier, he was a Lehman Fellow in the Social Sciences Department at the State University of New York at Buffalo, where he received a doctorate in economics.

▪ By picking up a telephone or tapping out keywords on a terminal, users of EPRI's Research and Development Information System (RDIS) have access to detailed information on some 3000 electric energy R&D projects. Begun in 1974 with a pilot data base from six utilities, RDIS now contains abstracts from some 90 companies and provides on-line computerized access. It is also serving as a tool to reduce duplication in research. RDIS manager Kenton Andrews and his staff supplied the input for **"A Key to Utility R&D Facts"** (page 18) by JOURNAL staff writer Stan Terra.

▪ It's a long jump from the 3000 research projects—past and present—in EPRI's RDIS to the 30 that are highlighted on these pages. But **"30 R&D Solutions: An Application Agenda"** (page 20), as the title suggests, isolates a special category: EPRI-sponsored findings that mark the beginning of

the Institute's payoff to its members and their customers. Winnowed through the cooperative efforts of the Research Advisory Committee and EPRI's planning staff, these projects are characterized by RAC Chairman Lud Lischer as "items of use to us today" or "far enough along that they should be considered for application in our present plans." Lischer's advice reflects the necessity—and the risk—of the next step: "Some of these accomplishments may not stand the hard test of use in the field, but we will know this only by application on our systems."

■ If you're a fan of *The Readers Digest*, you know about the cool wind of resistance to change that blows through the State of Maine. It's often documented by the laconic quips of "down easters" in the humorous anecdotes scattered among *Digest* articles.

Well, it's not true. The evidence is **"Peter Bradford: Perspectives on Energy"** (page 28), which documents the conjunction of an energetic young utility commissioner and a rejuvenated view of the regulatory function born in this decade from such newly urgent issues as consumerism, inflation, and the Arab oil embargo. Bradford's perspectives were captured for the JOURNAL last April by Marie Newman of the EPRI News Bureau.

Now, as this issue is prepared for publication, Peter Bradford may be moving to yet another position of regulatory overview: In mid-July he was nominated by President Carter to serve on the Nuclear Regulatory Commission.

■ In the continuing effort to boost power plant availability and capacity factors, in-service inspection is a key function. For nuclear plants, it is important not only because it improves these measures of reliability but also because such vigilance is the price of safety. Tolerances are tighter, stresses are greater, instrumentation is more complex, monitoring and record keeping are more extensive. The result is a recognized need for **"Evaluating the Performance of In-Service Inspectors"** (page 61).

In EPRI's Nuclear Power Division, **Eugene R. Reinhart** heads R&D for in-service inspection methods. A project manager in the Systems and Materials Department since 1974, Reinhart has a solid background in his specialty. He began six years' work as a design and research engineer at the Rocketdyne Division of Rockwell International Corp. in 1962, after earning a bachelor's degree at the University of Texas and a master's at the University of Southern California—both in mechanical engineering. In 1968 he went to Southwest Research Institute as a senior research engineer specializing in remote inspection systems, and in 1972 he became program manager for the development of nondestructive examination techniques for in-service inspection.

Schmidt

Lawrence

Reinhart

Coal: Keystone of Energy Fuels

by Richard A. Schmidt

How much coal? How soon? A rigorous new assessment of our accessible coal inventory emphasizes the importance of understanding how coal production is influenced by government policy, technology, pollution controls, and coal industry outlook.

☐ An EPRI state-of-the-art feature

Coal, the fuel that powered the industrialization of the American economy, is receiving renewed attention as the nation seeks domestic resources to satisfy future energy needs. But if coal is to regain its position as the keystone of U.S. energy fuels, a better balance is required in dealing with several factors that control its production and consumption: issues of policy, of technology, of environmental controls, and of coal industry outlook. Each of these—as well as all of them together—is of great importance to the electric utility industry.

How much coal?

Basic to any assessment of coal development issues is a foundation of fact (or, at least, of agreed assumptions) as to the size of the resource, its quality, and how fast it can be produced and used.

Despite hundreds of years of coal mining, our understanding of coal quantity remains imperfect. To begin with, we distinguish between the total amount of coal deposited by nature (which geologists call resources) and the portion that can be developed for use (which they call reserves). Resources can be estimated or postulated on the basis of geologic knowledge. Reserves, however, are by definition more precisely measured as to quantity and cost of mining by specific means. The U.S. Geological Survey maintains information on all designated coal resources, and the U.S. Bureau of Mines is responsible for compiling estimates of the coal reserve base in measured and indicated deposits.

Demonstrated reserves are well cataloged: measured quantities in the thickest seams at depths less than 305 meters (1000 feet). Even so, not all

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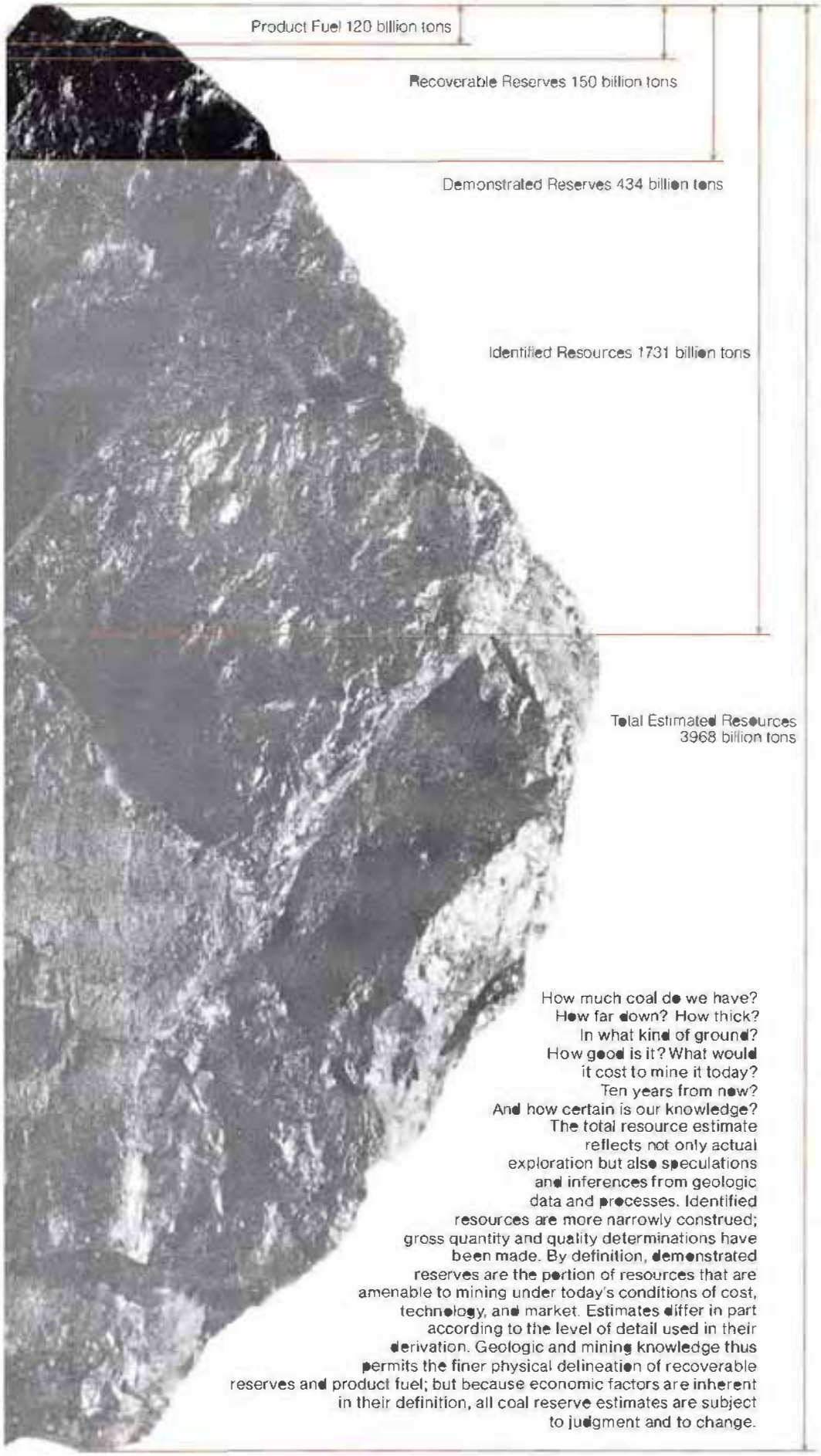


How much coal do we have? How far down? How thick? In what kind of ground? How good is it? What would it cost to mine it today? Ten years from now? And how certain is our knowledge? The total resource estimate reflects not only actual exploration but also speculations and inferences from geologic data and processes. Identified resources are more narrowly construed; gross quantity and quality determinations have been made. By definition, demonstrated reserves are the portion of resources that are amenable to mining under today's conditions of cost, technology, and market. Estimates differ in part according to the level of detail used in their derivation. Geologic and mining knowledge thus permits the finer physical delineation of recoverable reserves and product fuel; but because economic factors are inherent in their definition, all coal reserve estimates are subject to judgment and to change.

such reserves can actually be extracted and used. In underground mines, for example, some perfectly good coal must be left in place simply as structural support between rooms and haulageways. Similarly, efficient extraction from one mine may alter stress conditions so as to preclude development of other seams in the same coalfield. Also, legal provisions limit mining beneath cities, parks, rivers, and previously mined areas.

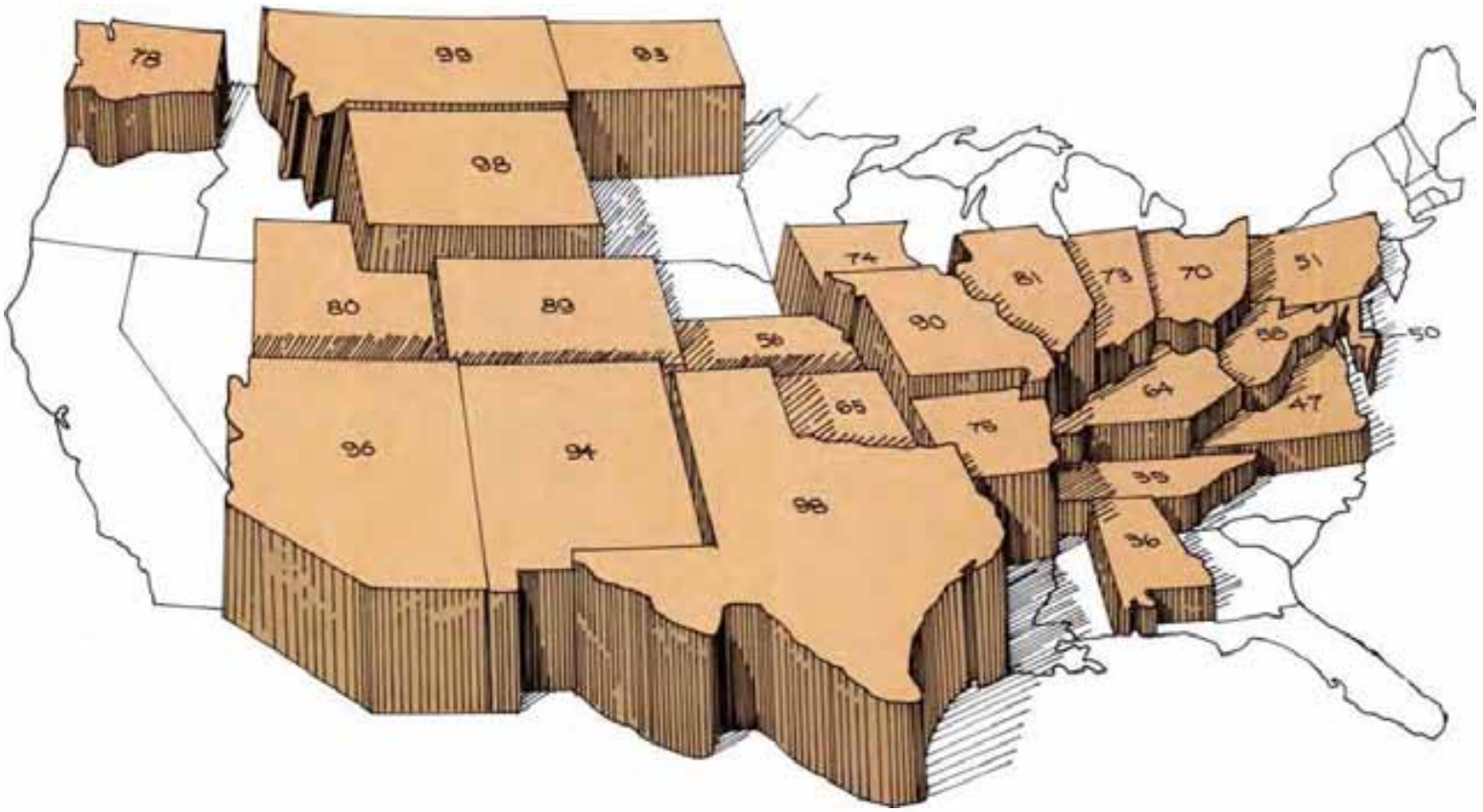
Frequently these and other restrictions on coal recovery are estimated, somewhat arbitrarily, to be as much as 50%, indicating a total recoverable U.S. coal reserve of somewhat over 200 billion tons.* But detailed studies by the author, assessing coal reserve data state by state (recognizing mining methods as well as discrete geologic data for individual mines and coalfields), suggest that such an assumption is liberal. The overall recoverability is closer to 33%, yielding a much lower reserve figure of 150 billion tons.

Finally, even the best coal-handling and -cleaning processes outside the mine also lead to losses. What we term product fuel is thus the important measure, yet it is as much as 20% lower. This ultimately usable net reserve appears to be about 120 billion tons (using production and beneficiation methods known today), or less than one-third the often-cited base of demonstrated coal reserves. But we now use 0.7 billion tons annually, and we are proposing to raise that figure to at least 1.0 billion tons in the next eight years. Clearly, even 120 billion tons would be exhausted in a relatively short time on history's time scale. In the author's opinion, there is a real need for intensifying exploration to better define the coal reserve base and for developing ways to recover coals that are not mineable at present.

Exploration of inferred and speculative deposits may increase the known recoverable reserves fourfold or more.

*1 billion tons = 1 gigaton.

Where are U.S. coal deposits? How much is left? In a state-by-state analysis, historic production totals were combined with current recoverable reserve figures to derive estimates of original quantities. Today's reserves are thus expressed as percentages. Western coal wealth is evident. Eastern coal depletion (under today's reserve definitions) is startling.



Additional coal may be discovered in areas not presently considered as coalfields. For example, analysis of data from oil wells in Kansas, Nebraska, Oklahoma, and Texas will probably extend the midwestern bituminous coal deposits farther to the west.

Better mining techniques and equipment should add to the reserve inventory, and it may also be possible to exploit coal reserves (other than by mining) through in situ burning processes to produce low-Btu gas. However, a recently prepared EPRI estimate is that even underground coal gasification would, at most, double the 120 billion tons foreseen as recoverable through mining from known deposits.

What future production can be expected? To approach a better understanding of how much coal can really be recovered, detailed data must be compiled, at least on a state-by-state basis. The results are, in some cases, startling. The best known deposits have been severely depleted in several states that depend heavily on coal as the mainstay of their economies: Alabama, Tennessee, Pennsylvania, and West Virginia. Of course, substantial inferred reserves remain. However, unless these are delineated and developed, or alternative activities established to replace coal, depletion of reserves (or even the prospect) could upset state and regional economies. Prohibition of coal development, it should be noted, can have the same economic effect.

On the other hand, reserve depletion is at a very early stage in many western coal-bearing states. Here the problem is to plan for development so as to conserve both the coal and the related resources, such as water, agricul-

tural acreage, and the soil itself.

In sum, the U.S. has large quantities of coal by any scheme of classification or measurement. But technical assessments today tell us that the foreseeable yield of processed, delivered fuel is a smaller proportion of demonstrated reserves than commonly estimated. Also, the state-by-state inventory of untapped coal reserves requires careful exploration and analysis. Both facts emphasize that coal, like other fossil fuels, is finite and its development calls for prudent planning. Any sudden rise in price due to a revision in the magnitude of recoverable reserves alone is highly unlikely.

How good is it?

The quality of coal has received considerable attention in recent years, mainly in relation to the chemistry of emissions (especially sulfur oxides) from coal-fired power plants. Because sulfur dioxide is subject to air pollution regulation, coals have come to be distinguished as much by their sulfur content as by their specific heating value. Most low-sulfur coals come from western coalfields, while those with a greater range of sulfur content come from the East and Midwest.

Intensive exploration for more low-sulfur coal supplies in the East has been undertaken in recent years. Also, major research effort is in progress to develop coal-cleaning technologies and emission treatments. But sulfur removal remains an elusive technology and has not yet been perfected.

There are, of course, numerous other coal-quality factors critical to plant performance: heating value; ash content, composition, and fusion temperature; and engineering properties (such as grindability) under operating conditions. These are often critical in determining whether or not a given coal can be used successfully in a particular plant, and they deserve greater attention. But all are overshadowed by the present focus on the emissions of sulfur oxides and other pollutants.

Coal in the years ahead

Projections of U.S. coal production and consumption vary. In analyzing these forecasts, it can be concluded that each (or none) is correct. Here we will concern ourselves with just two: the National Electric Reliability Council (NERC) projection of future coal consumption by electric utilities and the National Coal Association (NCA) projection of planned coal supply for the utility market. These estimates are timely, their sources are knowledgeable, and they draw on individual producers and consumers to compile totals (rather than assuming growth rates or deriving equivalents in terms of other fuels).

According to present plans, electric utility coal production and consumption are forecast to be in a close balance over the next decade. Noteworthy is the finding of the National Coal Association that coal will be used where it is produced, with little interregional movement between east and west. Eastern coal output will increase at only a modest rate, with much new production needed to replace depleted mines. When these estimates were made, the larger increase was seen to be in the West. The administration's national energy policy, if accepted by Congress, will result in greater use of eastern coal, altering the relationships forecast by NERC and NCA. The ease of establishing a new balance in response to this changed condition remains to be determined because of basic matters of coal quantity and quality, as well as an array of factors influencing coal development.

Winning against uncertainty

Deceptively simple in concept, the activities of coal production still constitute an art or a craft more than an exact science. They are replete with uncertainties in such fundamental elements as deposit characteristics, mining conditions, and coal character, not to mention labor relations, market economics, equipment performance, transportation availability, financial security, and government regulation. This array of uncertainties is such that coal production was formerly described as "winning." The term reflects the struggle of coal producers against the imperfectly understood processes of nature that created the deposits they labor to exploit. Reducing these uncertainties requires knowledge of at least the following factors that influence coal development: policy, technology, pollution control, and industry outlook.

Policy

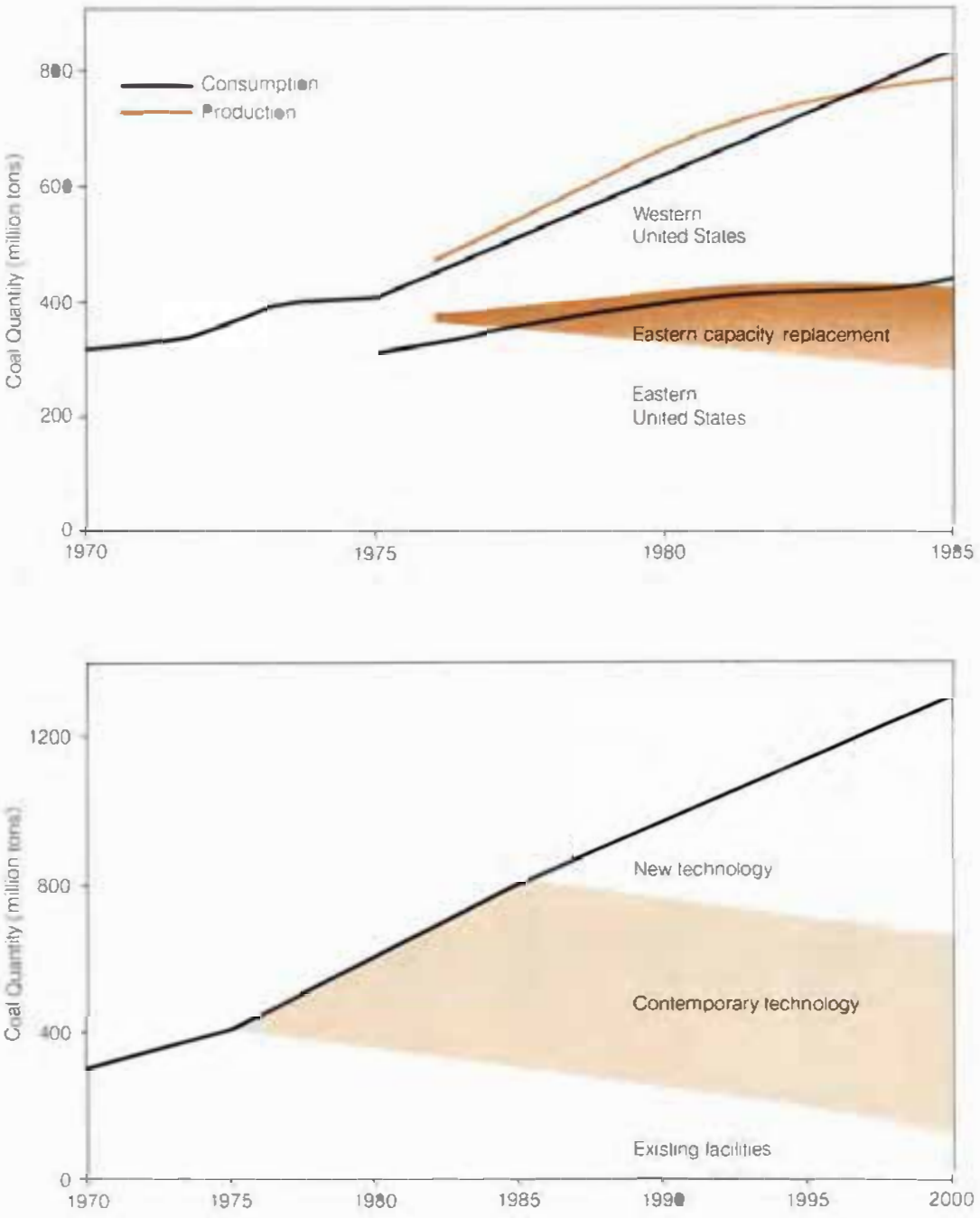
Many attempts to form a national energy policy have been advocated and undertaken in recent years; the latest was announced by the president in April of this year. Without embracing or rejecting these latest proposals, which are still being considered by Congress, it is possible to analyze the thrust of the provisions concerning coal.

In the principles enunciated by the president, emphasis is placed on shifting from scarce fuels to coal. A specific goal is to increase annual coal production by more than 400 million tons* by 1985, from nearly 700 million tons today. It remains to be determined whether the transition will be essentially voluntary, encouraged by various tax incentives, or mandated under the authority of the Federal Energy Administration (FEA) as part of a new Department of Energy.

The relation of expanded use of coal to protection of the environment (also a principle of the president's program) needs to be assessed. We don't know whether the rising concern over particulate control will influence the final environmental control program or whether alternative pollution control strategies will be available. Among these are coal conversion processes to produce "clean" fuels, improved combustion methods, and the use of combined-cycle generating systems. If scrubbers are required for both new and existing coal-using power plants, we could experience a shift in forecast patterns for regional coal production

*1 million tons = 1 megaton.

Where will electric utilities get coal, and where will they use it? The trend of annual production for utilities is upward to nearly 800 million tons by 1985 in this National Coal Association forecast. Western coal quadruples to 400 million tons annually in the period. The net from eastern coalfields is nearly level, although by 1985 there are over 150 million tons from new developments to replace retired facilities. The National Electric Reliability Council's forecast of utility requirements in the East and in the West tracks well with NCA's projection, indicating little interregional coal movement. But national energy program proposals now before Congress may require these forecasts to be altered.



How do we double annual coal production between now and 1985? Most significantly, we do it almost entirely by wider use of the technology and methods known today, and we replace worn-out facilities at the same time. The lead time for R&D and commercialization of markedly new technology is at least eight years. Thus, the impact of that technology by 1990 or 1995—or any distant year—depends on how soon the "window" of new technology can be opened.

and use. The prospective advantage of low-sulfur western coal in midwestern or eastern markets would be reduced or eliminated, slowing the pace and scale of western coal development. Because the federal government owns the principal western coal reserves, their development will continue to be closely controlled. In sum, the relatively undeveloped West, rich in low-sulfur coal, is market-limited. There the question will be, "How fast is it necessary to increase production?"

At the same time, greater levels of production of higher sulfur, higher heating value midwestern and eastern coals would be encouraged because of proximity to consumers and lower transportation costs and because scrubbers will probably enable these coals to satisfy air pollution control objectives. Eastern coal is largely owned by private organizations or individuals; in the further development of reserves, they face a challenge to avoid adverse social and environmental effects from the operations themselves or from the exhaustion of deposits where extraction is already well advanced. In contrast to the West, the East is resource-limited, and the question there will be, "How slowly may we increase production?"

Clearly, the proposed goals for coal are consistent with the principles of the administration's energy policy in that environmental quality would be served by slower-paced western coal development and by mandated emission controls, and economic redevelopment in the midwestern and eastern coalfields would be served through intensified coal development and use.

Technology

Today's technology for coal production and use—for the most part—evolved from a history of engineering empiricism and trial and error. Marked or widespread change is unlikely throughout the remainder of the twentieth century because if any new technology were to have significant impact on coal production within 10 years, it would

have to be in the hands of the mining industry today. William Poundstone of Consolidation Coal Co. said it flatly: "New technology won't give us any overnight solutions. It took the coal industry years to refine the continuous miner and make it worth the sizable investment involved."

An analogous situation exists with respect to technologies for coal conversion and use. This reality was emphasized by Richard Balzhiser, Director of EPRI's Fossil Fuel and Advanced Systems Division, in testimony before the U.S. Senate's Committee on Energy and Natural Resources: "The principal form will continue to be pulverized coal, directly fired to raise steam for electric power generation."

Looking ahead, it is possible to delineate the role of existing coal technology in serving electric utility requirements. Many of today's facilities (mines and power plants) will have been retired as the end of the century approaches, although some will remain in service beyond 2000. For at least the coming 10 years, the opening of new mines with technologically current equipment can be expected to compensate for those retirements and to satisfy growing demand. Assuming that new technology is perfected and demonstrated according to current R&D plans, the earliest opportunity for new technology would appear to be in the late 1980s or early 1990s. In view of this, it seems worthwhile to devote special efforts toward incremental improvement of today's technology so that it can—as it must—carry the bulk of the load for this quarter century.

Examples of the kinds of improvement needed are the U.S. Bureau of Mines' programs for development of an automated extraction system (combining roof supports with a continuous mining machine) and Consolidation Coal's effort to perfect hydraulic transportation of coal from underground mines. While these are advances over present practices, they are not complete departures, as are concepts for outfitting coal miners with "space suits" or using chemicals for coal extraction.

Pollution control

Mitigation of pollution to the physical environment has become a strong influence on all aspects of coal development and use. After a long struggle between the coal industry and an active coalition of groups concerned about the environment, a federal strip mine control law has been enacted. The law establishes uniform minimum surface mining and reclamation requirements. Many of these requirements (especially those pertaining to rehabilitation of mined lands or prevention of pollution from active operations) already exist to some degree in state laws and regulations and in operating requirements for federal coal leases.

Although the provisions of this law may lead to somewhat higher production costs and restrict development of certain deposits, an analysis sponsored by FEA suggests that these effects will be relatively small. Now that the issue is resolved, the energies directed toward the pollution control debate can be refocused on improvements in reserve recovery and productivity.

The controversy over means to control pollution from coal-using facilities, however, continues unabated. Unless it is resolved soon, expanded coal use is still unlikely, leaving the nation vulnerable to increasing petroleum imports. Exhaust gas scrubbers for sulfur oxide control, which lead to higher capital costs and somewhat reduced plant efficiency, are required for most new coal-fired plants under today's performance standards for such new sources.

As with strip mining, having a known regulation in effect, even though not the preferred one, can be a constructive resolution that permits progress. But a requisite for the installation of scrubbers (or any pollution control strategy, for that matter) is that the requirements be clear, consistent, and specific and that they not change appreciably (if at all) during the useful lifetime of a power plant. Provision for scrubbers is being made in the design and construction of new plants, but demonstration of their operability and assurance of stability in the standard-setting arena is needed before they will be universally accepted.

An innovative and potentially productive group has been formed to address environmental policy matters that have ramifications in the economics of coal technology and of coal-producing regions. During the past year the National Coal Policy Council has brought together the National Coal Association, The Sierra Club, Consolidation Coal Co., Friends of the Earth, Peabody Coal Co., and others of widely divergent views on coal development. It may be worthwhile for electric utilities—who collectively consume two-thirds of U.S. coal production—to add their voice and viewpoint in this forum.

Outlook and implications

The nature of coal, its whereabouts, quantity, and quality, may be expected to control the manner of its use. As in the past, most coal will be used in the same region as it was produced. Established patterns of development will strongly influence the location and scale of future activities. And for at least the remainder of the century, both coal production and use will depend on the expanded deployment of existing technology, with the role of truly advanced technology being small.

Since the technical timetable is largely independent of changing needs and necessarily proceeds at a more measured pace, coal producers, users, and regulators must be innovative in stabilizing the conditions under which they compete and cooperate to fill consumer needs. Knowing and understanding viewpoints, and appreciating their origins and differences, are perhaps the most important contributions each can make in restoring coal as the energy keystone.

Load Forecasting—Modeling With Judgment

by Anthony Lawrence

Accurate load forecasting has become increasingly important to electric utilities, but the accuracy of load forecasts has left much to be desired. Recent improvements in computer efficiency and the development of sophisticated forecasting methods show promise for solving this intricate problem.

The premium placed on accuracy and the difficulty of forecasting both stem from the same set of factors. Throughout the 1950s and 1960s, energy and load requirements grew steadily and accurate projections could be made with simple statistical models. Aggregate peak load and energy use models, which took into account a few key economic and demographic variables, produced fairly accurate forecasts. These forecasts owed their accuracy to the fact that energy was cheap, economic growth was steady, and relative energy prices were stable, so there were no incentives for dramatic changes in energy use. Traditional methods were adequate, and little attention was paid to developing or implementing new forecasting approaches.

Throughout this period the demand for electricity rose much faster than the rate of economic growth due to a gradually falling real price level for electricity and a simultaneous shift to electricity as a cleaner and superior form of energy.

In the early 1970s the energy picture began to change, slowly at first, then explosively. Pent-up economic forces created during the Vietnam conflict caused rapid inflation and economic dislocation. The steady economic growth of the 1960s ended. Energy prices increased slowly as supplies tightened and as air quality regulations changed energy demands in favor of expensive low-sulfur coal and imported oil. Finally, the OPEC oil embargo shattered the market, transforming already serious domestic energy problems into the energy crisis.

Simple preembargo methods of load forecasting are giving way to sophisticated statistical modeling that promises more reliable load curve projections.

▫ An EPRI program article

Anthony Lawrence is an economist and project manager in the Demand and Conservation Program of EPRI's Energy Analysis and Environment Division

Failure of old methods

As aftershocks from the energy crisis resounded through the economy, reliability of energy demand and consumption forecasts tumbled. New forecasts repeatedly missed the mark. Traditional methods of forecasting, which relied on the correlation of a few variables or the extrapolation of existing data, failed to produce credible results for utility managers and public policymakers. The forecasts failed when they were most needed —when private industry and government were redesigning policies for energy production, distribution, and use.

Uses of forecasts

Load forecasts have many different uses. The intended use of a forecast determines its time horizon into the future and its level of detail. Generally, the longer the range of the forecast, the greater the need for detail. This general rule rests on the fact that more and more factors are subject to change the further one projects into the future. For short-run forecasts, all these complicating factors can be ignored in favor of factors that have marked short-run variation, such as weather.

In the long run, virtually all economic and technological parameters may change. An understanding of the long-run impact of these changes on the load pattern requires load models for specific end uses and locations. Perhaps the best testimony to the importance of economic and technical change is the historical

Utility system forecasts may vary in length from 3 hours to 50 years, depending on their purpose. The longer the time span covered, the greater the depth of detail required; the further into the future the projection, the greater the probability of a change in the determining factors. For short-run dispatch scheduling, for instance, the forecaster can concentrate on short-range variation in factors such as weather. For longer-run projections, determinants that change over time, such as economic growth, resource availability, and developing technology, need to be considered.

Depth of Detail	Length of Forecast			
	Short run (3 hours–3 days)	Medium run (1 day–2 years)	Long run (1 year–15 years)	Very long run (10–50 years)
National, regional, or system load	Dispatch scheduling	Maintenance scheduling Distribution planning	Generation planning Transmission and distribution planning Revenue and rate planning	Research and development planning for new production, distribution, and utilization technologies
Customer class or other division of system load				
Individual customers				
Individual production process or energy-using appliance				

experience of air conditioning. In the post–World War II period, its rapid market penetration changed many utilities' annual peak demand from winter evenings to summer afternoons. Looking into the distant future, the load forecaster must be alert for similar load-shifting innovations.

Varied ranges

The range of load forecasts varies from a few hours to fifty years. Short-run forecasts, ranging from a few hours to a few days, are made for dispatching electric power. Most utility companies or power pools have economic dispatch models that schedule generation equipment to be brought into service in a three-hour to three-day period. Medium-term forecasts, from a few days to several months, schedule maintenance, renovation, and installation of generation equipment.

The uncertainty associated with short- and medium-run forecasts affects system reliability. Power system reliability is the probability of the system's meeting total customer demand.

If the actual demand is much greater than the demand forecasted, it may overburden the system and cause outage. All else being equal, the more uncertain the load forecast, the more standby equipment is required and consequently, the higher are the capital and operating costs to maintain the level of service. It is economically important to both producers and consumers of electricity that the uncertainty of load forecasts be reduced to the smallest possible level by using the best data and methods.

Long-term load forecasts, from a few years to a few decades, are used for utility system planning and revenue projections and as aids in rate design. Both the amount and the composition of generation, transmission, and distribution equipment are determined by load forecasts. The total planned capacity of the system must exceed the forecasted peak load by a reserve margin to maintain system reliability. Generation equipment is composed of baseload, intermediate, and peak load generators. The proper proportions for each type of equipment depend on the shape of the forecasted load. (The relationship between load shapes and capacity proportions is discussed in the EPRI JOURNAL, May 1977, p. 6.)

Revenue projections derived from long-run load forecasts must be matched with the capital requirements for system expansion. Rates are designed to produce adequate revenues and manage the system load shape.

Research decisions about new technologies to produce and use electricity must be made far in advance of their entry in the marketplace. Very long-run load forecasts are useful in making R&D decisions. For instance, if some fortuitous combination of forecasted future demands resulted in a flat load profile, it would no longer be necessary to develop large-scale storage battery technology. Such R&D concerns are of primary importance in EPRI's load forecasting research.

The new premium placed on forecasts derives from their value in decision making for conservation, load control, and technological change. The present scarcity of energy and capital has given greater importance to these areas.

Conservation

Accurate load forecasts promote conservation through the efficient operation of the power supply system by providing information for power dispatching, by contributing to the most efficient design of the generation and distribution system, and by aiding R&D decision making about future technologies for the supply and use of electric power. Inaccuracies in the dispatch forecasting model on the high side of actual demand cause excessive operating costs and fuel consumption, while inaccuracies on the low side of actual demand require the purchase of power from neighboring systems, the shedding of interruptible customers, or voltage reductions in the system.

If future load forecasts show that system loads will be relatively level, then the future generation mix will be more heavily weighted with baseload equipment powered by coal or nuclear fission than with equipment of greater cyclic capabilities, which require expensive oil or gas fuels. Similarly, the unevenness of the forecasted load pattern should be a determinant of the research priority for load-leveling devices.

Controlling the load curve

Load management is a generic term for policies pursued by electric utilities to control the shape of their load curve. Load control measures may be characterized as hard or soft. Soft load control measures rely on customers to respond to economic incentives. Hard load control measures are designed to give the electric utility dispatcher physical control over the amount of load available for particular end uses by specific customers at each point in time. Forms of soft load control are electricity prices that vary by time of day or by season and rate schedules that have separate charges for energy use and peak demand. Two forms of hard load control are interruptible agreements with industrial users and ripple control, which allows the utility to shed specific appliances by sending a small electric impulse over the power lines.

For a load control measure to be efficient, it is necessary to forecast load accurately. Soft load control requires measurement of the effects of alternative rate designs on load shape. For hard load control, the time pattern of the interruptible load must be known to measure the impact of load shedding on the system load curve.

Technological change

Detailed load analyses are necessary to determine the impact of new energy-using devices on electricity load. The effects of new energy-using processes and appliances on the load pattern are criteria for assessing the desirability of developing and promoting new technologies. Thus, the load dynamics of new electric goods, such as electric vehicles and heat pumps, are of major interest. New methods of generating power become

feasible by technological research and development. One factor in evaluating the economic desirability of potential generating technologies is the overall load pattern that must be served by new technologies in tandem with existing technologies. For example, if a new generator is capable of being turned on and off rapidly, then it will have its greatest value if the system load is highly variable.

Technological change in energy-using equipment is also related to accurate load forecasting through its effects on the regional growth or decline of specific industries. As the industrial composition within any one region changes, the load pattern of the region changes. For the utility to plan and cope with its changing industrial load, the load forecasts should be directly related to industrial composition and technical changes.

Methods and data

There are several methods of load forecasting. The best method for a given situation depends on the use of the forecast and on the time and effort available for developing it. Ideally, the time and resources put into the forecasting effort are balanced against the expected value of the information to be gained from the forecast.

Generally, three types of information are available to forecasters: historical data, engineering data, and intuition or judgment. Historical data include time series of observations on economic and environmental variables and observations on the same variable over a cross section of similar units. The most important data for short-run load forecasting are the load's own history and time series of weather variables. For longer-term forecasting, cross-section data on economic variables such as income, prices, and employment are desirable for development of statistical models of the load pattern. Engineering data include theoretical and empirical knowledge of the operations of various energy-using processes. For instance, the load pattern of heat pumps can be described mathematically by using physical principles and it can also be measured by automatic recorders. In principle, both should agree.

No load forecast is complete without the judgment of the forecaster. Pure intuitive or judgmental forecasts are primitive in the sense that they cannot be reproduced objectively. However, they should not be disregarded, since they often include experience with factors that cannot be easily quantified. Judgmental forecasts of certain key variables can be regarded as a test of the reasonableness of an econometric or engineering model.

Techniques exist that allow for judgmental forecasts to be explicitly incorporated into the estimation of a load forecasting model. When reliable judgmental forecasts are available, they enhance the value of carefully constructed statistical models that include both the behavioral and the technological structure of energy use. Mathematical models that can incorporate judgmental forecasts can be especially valuable in assessing the implications of public policies, rate designs, economic growth, and technical change on the total load pattern.

Engineering accounting methods develop load forecasts by enumerating the number and type of energy-using appliances and then multiplying each appliance by its energy requirements and frequency of use during every time period. The load pattern is then constructed by adding up the energy used in all appliances for every time period. Forecasts using this technique are developed by extrapolating into the future the numbers or saturation rates of all the appliances.

Engineering process models are more sophisticated than engineering accounting techniques. Process models are mathematical descriptions of how a particular item is produced or some need is satisfied. A process model includes mathematical equations describing technological and behavioral relationships and operating constraints or restrictions. Process models can yield predictions of the time and intensity of energy demand for specific methods of energy use as a function of the process's output and its environment.

Cogeneration

Under the proposed energy program, load forecasting will be complicated by increased cogeneration by industrial customers. This problem can be analyzed by developing load projections based on engineering process models of the industries involved. Such models will have to account not only for the industries' demands for power from the utility systems but also for the industries' supply of power to the grid. A process model can project the pattern and intensity of the power demands or supplies resulting from the industry producing its primary product.

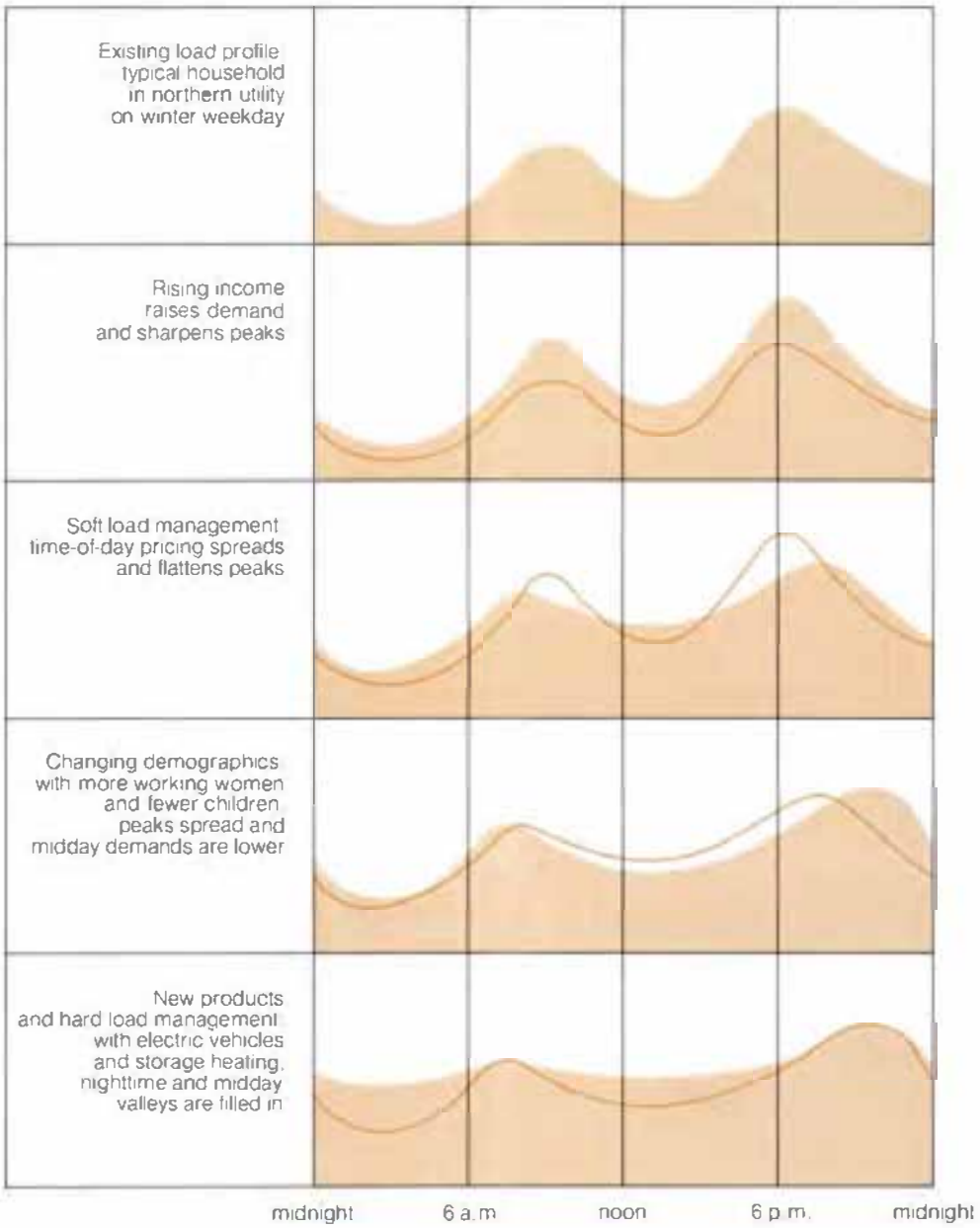
Scheduling in most industries is dictated by social customs, such as the eight-hour workday, and by the nature of the industrial process. Deviations from both are possible at some cost, such as overtime pay, but will be made only to minimize costs of production. Thus, there is a potential for electricity rate structures to be manipulated to induce cogenerators to demand and supply power to the grid at economically efficient times.

Historical data

Models that rely on historical data may be subdivided into time-series models, aggregate econometric models, and microeconometric models. Time-series models differ from econometric models in a fundamental way. Econometric demand models specify the behavioral and technological structure of energy demand, relating it to other economic and social variables. Time-series techniques analyze the behavior of each variable over time and attempt to predict the variable's future based on its past behavior. Neither method is a complete paradigm for all forecasting tasks, and they can be combined to produce hybrid models. Both techniques, separately or in combination, must be tempered with generous measures of physical knowledge and good judgment to produce superior load forecasting models.

Generally, time-series models forecast the future values of an economic variable

Long-run residential load forecasting requires models of many behavioral and technological factors, including rising family income (which sharpens peak demand) and such changing demographic patterns as more working women with smaller families (which tends to lessen daytime demand). Offsetting these factors will be new uses of power, such as electric vehicles and storage heating. Utilities need to promote desirable residential load shapes by encouraging new uses that create off-peak demand and by controlling demand through "soft" pricing incentives or "hard" direct load control of such major uses as water heating and space conditioning.



as a function of time and the variable's own history. In the construction of a forecast, these models take advantage of trends and recurrent patterns that are evident in the variable's history by replicating them into the future. The simplest class of such models includes linear and exponential trend models.

Sophisticated time-series methods include Box-Jenkins methods, spectral analysis, Fourier series, and periodic spline functions. These methods provide neither a structural explanation of the causal relationship between the variable being forecast and other variables nor insight into how the variable might be subject to control. Time-series methods, however, do have a useful role in load forecasting. In the short run they are quite accurate and require only limited data, analysis, and computer time. These economies stem from the fact that the history of only one variable, the variable being forecast, is required.

There are multivariate extensions of time-series methods. However, these methods are more difficult and expensive to use than single variable time-series models. It is difficult to interpret the causal meaning, if any, of the interrelationships between variables in a multiple time-series model. However, these methods deserve further attention for electricity load forecasting, especially in short-run situations where there are only a few variables of interest.

Econometric forecasting

Time-series models are most useful in the short run. For forecasts of one to five years, aggregate econometric methods are adequate for most purposes. They can capture important interrelationships between variables when there are few fundamental technological or structural changes at the microlevel.

To capture long-run changes in a load forecasting model it is necessary to analyze detailed behavioral and technological data. Ideal econometric load forecasting methodology requires the forecaster to combine well-reasoned behavioral theory with detailed engineering information in formulating the model. This perspective does not limit the econometrician's tools to classical economic theory and multivariate regression but includes the vast scope of mathematical and statistical methods, behavioral postulates from other disciplines, and engineering information.

Forecasting residential loads

The residential load profile typically has two peaks during the day—in the morning and in the late afternoon or early evening. Winter heating and lighting loads shift the evening peak a few hours later and flatten the nighttime valley somewhat. Summer air conditioning advances the evening peak to the afternoon and partially fills the daytime valley.

Individual household load data can be combined with weather data and survey data on household characteristics to produce high-quality load projections. The household characteristics include an enumeration of appliances, type of dwelling, and the demographic and economic characteristics of the family.

When combined with models of appliance choice, these load forecasting models aid in evaluating the impact of changes in the efficiency or quantity of electrical appliances. The models can be extended to evaluate the load impact of such new electrical devices as solar-assisted heat pumps or electric automobiles. It is possible that both would fill the nighttime valley in residential demand.

The reshaping of the load pattern resulting from secular changes in demographic and economic characteristics can also be estimated. Two important trends are the rising participation of married women in the labor force and the decreasing number of children per household. These trends should result in a deepening of the daytime valley and a spreading of the peaks as the family rises earlier and retires later.

The effects of both soft and hard load management policies on the residential load shape can be incorporated and measured with a detailed econometric model. Time-of-day pricing is the most frequently discussed soft policy for residential load management. Early results using data from federally sponsored experiments indicate significant load shifting as families readjust their schedules to avoid high peak period rates. While this is encouraging, it does not diminish the potential role for hard policies to manage residential loads. Some utilities and their customers have already enjoyed considerable economies from ripple-controlled water heating. Recharging electric vehicle batteries is a likely candidate for direct load control in the future.

New methods

The development and the implementation of new load forecasting methods are progressing rapidly. Some new methods rely on the firm foundation of statistical time-series theory, some are built from engineering process models, and others result from microeconometric analyses of electricity users' behavior. The new methods are more complicated and sophisticated than the preembargo forecasting techniques that have proved inadequate. Time-series methods are useful for short-run forecasts and will replace simple trend extrapolation techniques. Process modeling and microeconometric modeling are promising for longer-run forecasting. These methods will supplement or displace engineering accounting techniques and aggregate econometric modeling.

The implementation of advanced forecasting methods is made possible by the ever-increasing efficiency and falling costs of computerized data manipulation. Despite these advanced techniques being inseparably tied to the computer, they are certainly not automatic or cybernetic forecasting tools. On the contrary, much as the development of delicate heart and brain surgery requires increasingly skilled surgeons, the implementation of sophisticated load forecasting methods requires ever more skillful forecasters. The forecaster's good judgment always has been, and always will be, the sine qua non of load forecasting.

A Key to Utility R&D Facts

RDIS serves the utility industry as an authoritative source of R&D facts and as an aid in reducing duplication of research effort.

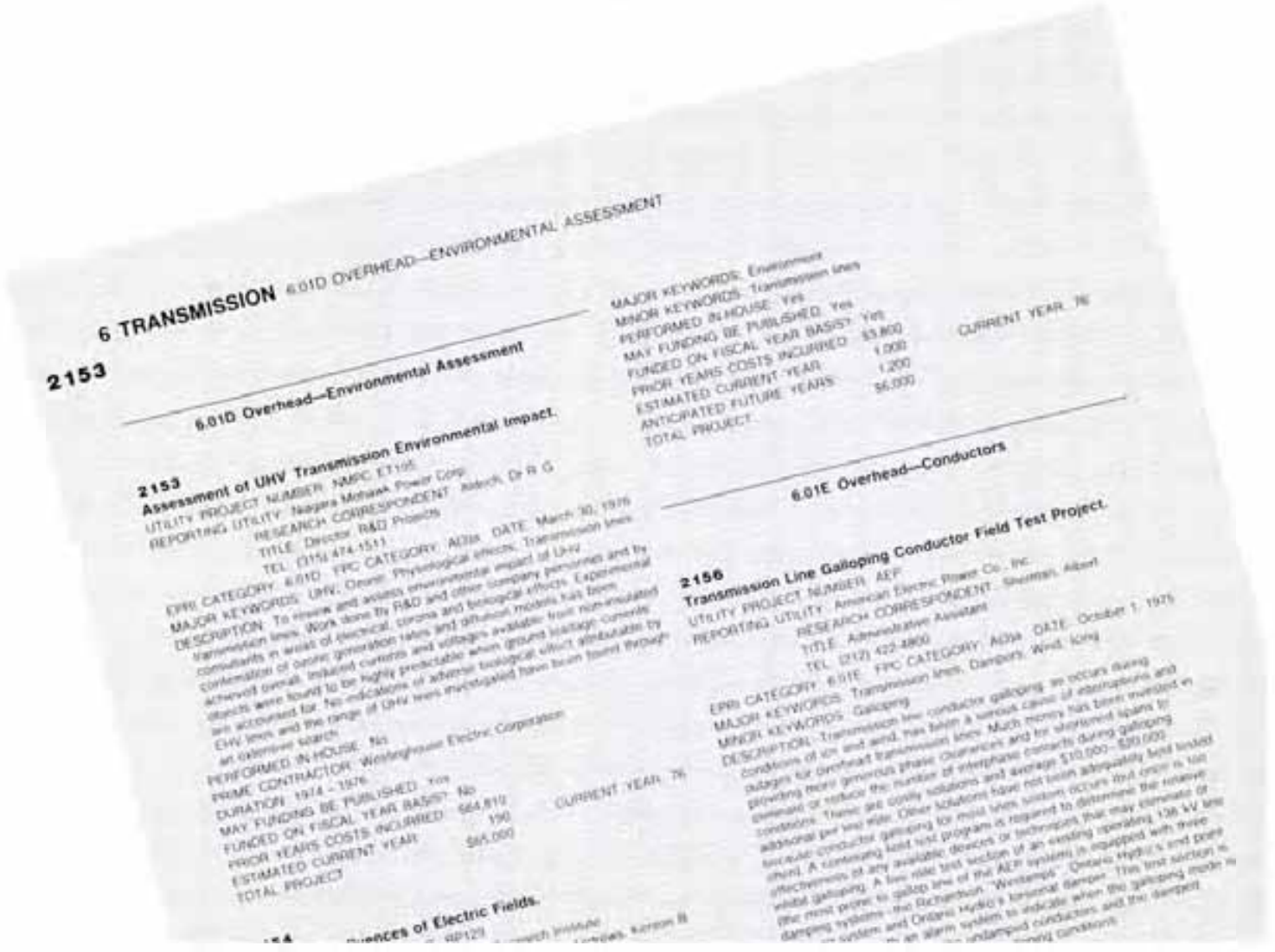
Tennessee Valley Authority instrumentation engineer Ernest Clauss called to find out if a project TVA was about to begin would duplicate EPRI's work on water reactor sensor time-response verification. John Buechler, an electrical engineer at Long Island Lighting Co., wanted to know if any research was being done to determine the effect of more home insulation on the use of residential air conditioners.

These are typical of the inquiries that come into EPRI's Research and Development Information System (RDIS) office in Palo Alto. About 50 such requests for information about electric utility R&D are fielded each month by the RDIS staff, according to RDIS manager Kenton Andrews. Andrews referred Clauss to the EPRI technical staff in charge of the project in question and, guided by information from the data base, gave Buechler contacts at Pacific Gas and Electric Co. and at a midwestern university for discussions of the air conditioning issue.

RDIS, established by EPRI in 1974 as a primary source of information about the R&D activities of EPRI and the U.S. electric utilities, contains details on approximately 3000 R&D projects under way or recently completed by some 90 organizations. RDIS was designed as a single authoritative source of electric utility R&D information to reduce the duplication of research effort and broaden the application of new and improved technology. Details about EPRI projects in the data base are updated monthly. Information is revised annually for the projects of other participating organizations.

The data base is computerized so that access is provided through a computer terminal linked by telephone and teletype lines through the Telenet communications system to the RECON IV program of Informatics, Inc. The central computer containing the RDIS data base is located at the Informatics facility in Fairfield, New Jersey. Many requests, however, come directly to EPRI by telephone or by mail. In such cases, the RDIS staff accesses the data base and supplies the inquiring party with a printout of the requested data.

The data base is organized in 13 major subject categories: general R&D support, hydroelectric power, nuclear power, fossil fuels, advanced power systems, transmission, distribution, stations and substations, customer utilization, economics, personnel, area development, and environmental assessment. Specific information about each project includes the project title; the name of the sponsor, research correspondent, and contractor;


6 TRANSMISSION 6.01D OVERHEAD—ENVIRONMENTAL ASSESSMENT

2153

6.01D Overhead—Environmental Assessment

2153
Assessment of UHV Transmission Environmental Impact

6.01E Overhead—Conductors

2156
Transmission Line Galloping Conductor Field Test Project

Influences of Electric Fields

the amount of funding, and a list of publications resulting from the research. For projects funded above $15,000 there is a technical abstract of the research objective and significant results. RDIS users may access information by utility project number; FPC category; EPRI subject category; the name of the reporting utility, prime contractor, or cosponsors; and/or keywords. For example, an EPRI report on trace metals in the New York City atmosphere can be accessed by the keywords *trace metals, air pollution,* or *copper;* by the EPRI project number RP117; or by the category number 13.01F, which covers all data records on ambient pollutants.

The entire data base is published annually as *Digest of Current Research in the Electric Utility Industry.* Some 3000 copies of the 1976 *Digest* have been distributed throughout the United States and to overseas electric utility research organizations with whom EPRI has bilateral agreements for the exchange of information. The *Digest* goes routinely to EPRI member utility chief executive officers, to member utility information coordinators, and to the approximately 300 members of EPRI's industry advisory committees, among others. It is widely distributed, on request, to manufacturers, government agencies, research organizations, and universities.

Information about new projects for the data base comes to the RDIS office from the utilities on a standard questionnaire supplied by EPRI. The information is recorded, using a Datapoint-1100 unit connected to a servoprinter that produces a printout. This printout is sent to the originating utility for verification of data before it is entered in the data base. The EPRI equipment enables the RDIS staff to perform off-line editing of the project information. About 150 new entries are made each month.

Andrews points out that the RDIS office is about to release a new publication, *Keyword Thesaurus,* which will assist the users of RDIS. "Its purpose," explains Andrews, "is to standardize access to the data base."

EPRI member utilities and those contributing project information to the data base are entitled to searches by the RDIS staff without charge. Those wishing to access RDIS directly through an interactive terminal pay Informatics an initial subscription fee of $100. The fee for computer connect time is $50 an hour, prorated according to the actual time used.

In addition to its data base activities, the RDIS office publishes a quarterly listing of EPRI's R&D projects. There are now some 960 EPRI projects listed—current, completed, and in contract negotiation. The entry for each project includes the project number, title, and shortened abstract of the purpose of the work.

"The success of RDIS," says Andrews, "depends on widespread utility participation. All electric utilities having R&D projects are urged to report them fully and regularly to RDIS to ensure that it will be a complete and accurate source of current information for benefit of the entire electric power industry."

A page from *Digest of Current Research in the Electric Utility Industry* (left). RDIS staff in Palo Alto check printout (below) accessed from the central computer in New Jersey and feed new data into system (right).

30 R&D Solutions: An Application Agenda

EPRI's Research Advisory Committee selects the research results that electric utilities can apply in their operations and planning now.

Today, just over three years since the Electric Power Research Institute began its research, we are seeing the benefits of our investment. EPRI is fulfilling its intended role in sponsoring coordinated research and development and in acting as an important utility industry contact with government and private agencies on matters related to R&D.

Research programs and results are carefully reviewed by the industry committees to ensure that R&D effort is focused on our most urgent priorities. For example, significant work is under way on important future fossil fuel and nuclear alternatives required to ensure the reliable operation of our generating units. Progress is also being made on developing an improved understanding of the environmental aspects of the industry, as well as the issues surrounding energy demand, conservation, and resource utilization. We can anticipate great long-term benefits from these R&D programs. At the same time, important results are being developed that will find more immediate application. Near-term development, which should be of value by 1985, accounts for about 50% of the Electric Power Research Institute's program funding.

It has also been helpful to be able to prove what will neither work nor be beneficial to the utilities and their customers. Programs such as flywheel and superconducting magnetic energy storage are in this category. EPRI has ceased work and phased out more than 18 projects of this type.

To reap the benefits of the R&D we sponsor, it is incumbent on us to see that these concepts and technologies are tested in the practical world of utility systems. Some of these accomplishments may not stand the hard test of use in the field, but we will know this only by application on our systems.

The desire to identify and present results of near-term projects in a factual manner prompted us to develop a list of some of EPRI's accomplishments to date. The list was reviewed and a careful selection of significant items was made by the industry committees and the EPRI staff. We believe these project results are representative of the current effort. Items of use to us today are included, as well as those that are far enough along that they should be considered for application in our present plans. The highlights of these accomplishments are presented on the following pages and are listed according to the key program areas used in our planning process.

- Resource Processing, including developments related to the processing of coal and nuclear fuels
- Energy Conversion, including fossil fuel, nuclear, and advanced conversion plants
- Electrical Systems, including electricity generation, transmission, and distribution systems
- Environment, Energy Management, and Energy R&D Analysis, including efforts directed toward environmental issues, conservation, and economic analysis

We hope this material will stimulate your application of these technologies. The industry committees are proud of the progress made on each of the programs, but our real satisfaction will come as we see substantial use of the results.

L. F. Lischer, Chairman
Research Advisory Committee

RESOURCE PROCESSING

High-intensity ionizer

A major step has been taken toward more efficient collection of fly ash from coal-fired boilers by the development of a high-intensity ionizer. Its unique electrode geometry establishes electric fields some five times higher than in conventional electrostatic precipitators. Five months of system

testing at flow rates to 2.5 m^3/s (5000 ft^3/min) with both medium- and low-sulfur coal confirmed the design: the ionizer and a three-stage collector reduced high-resistivity particle penetration by 70%. A commercial prototype is being tested at 16.5 m^3/s (35×10^3 ft^3/min) this summer, and TVA is retrofitting a 140-m^3/s (3×10^5 ft^3/min) passage at its Shawnee power plant. Ionizers are to be commercially manufactured under license from EPRI. For new installations, the forecast is that they will cut costs by 25–30%; for retrofits, they should cut costs by about 60–70%. (RP386)

Electrostatic precipitator

Improvements in techniques for accurately predicting the efficiency of electrostatic precipitators have resulted from EPRI-sponsored field tests at six utility sites. The tests showed that large fractions of total particulate emissions occur during precipitator rapping cycles (about 30% for cold-side precipitators, 60% for hot-side). Rapping losses occur for the most part in the larger particle sizes, primarily as particles larger than 2 μm diam. However, rapping losses from both hot- and cold-side precipitators are major contributors to the overall penetration and illustrate that significant improvement in mass efficiency may be possible by optimizing the rapping system design and programming. The tests also increased the reliability of a computer model commonly used in predicting precipitator performance. (RP413)

Bag filters for particulate control

Because stringent particulate standards are stretching the performance capability of electrostatic precipitators, fabric filters have been investigated as an alternative. To determine fractional efficiency, measurements of particulate size and composition were made at filter inlet and outlet. Continuous measurements of opacity at those points permitted correlation of aerosol capacity with such events as boiler

upsets, filter cleaning cycles, valve actuations, and so on. Test results show that fabric filters achieve the highest efficiency now possible for particulate control, especially for high-resistivity fly ash. Mass emission data at half and full load reveal that efficiency is typically 99.9% for 0.02–2-μm diam particles, though some larger particles seep through at full load. Plume opacity is virtually nil, ranging as low as 0.02% (equivalent to 13-mi visibility). (RP534)

Flue gas desulfurization

High-velocity scrubbers have the potential for reducing the capital cost of emission control equipment by cutting the number of scrubber modules needed. Two advanced units should equal the capability of four

countercurrent vertical scrubbers and at about half the cost. A 1-MW pilot facility on the TVA system has been used to test the cocurrent and horizontal scrubbing concepts. In related research, reheaters and demisters have also been evaluated: reheaters because they use 25–50% of the scrubbing system energy input and demisters because their reliability is key to system success. Tests results show that the cocurrent scrubber uses about half the energy of a countercurrent scrubber for equal performance in SO_2 removal. This concept has been selected for use with high-sulfur coal in a 10-MW TVA pilot facility. The horizontal spray is being used in an Ohio Edison Co. scrubber design. (RP209-2, RP537)

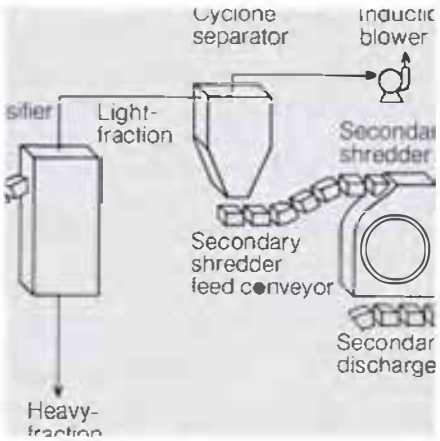
NO_x control

In anticipation of more stringent standards for NO_x emissions from coal-fired plants, field tests were conducted to assess the relative effectiveness of windbox gas recirculation and staged

combustion for NO_x control. The boiler used was a 550-MW unit firing high-sulfur eastern coal. The effects of stage combustion on boiler operability were also evaluated on a 750-MW boiler firing low-sulfur western coal. During the 18-month study, measurements were made of NO_x, polycyclic organic materials, and total particulate and size distribution, as well as observations of slagging, fouling, and furnace wall corrosion. Tests results indicate that windbox gas recirculation is relatively ineffective compared to staged combustion in controlling NO_x, and it also carries a 1% penalty in boiler efficiency. (RP529, RP530)

Solid waste as a boiler fuel

The feasibility and other aspects of using fuel derived from municipal solid waste for firing power plants were investigated by EPRI. The study showed that utility involvement in municipal solid waste disposal raises financial, legal, and institutional problems that outweigh the technical considerations. Three case studies describe how utilities have dealt with these issues. The study report outlines the options available and under development for use of solid waste in power production. It describes the problems dealing with efficiency, cost, and technology so that utilities can use this information to respond to requests from local communities for help in solving the solid waste disposal problem. It was found that energy efficiency of waste shredding and supplemental firing would be about 29% if used in a plant with a 43% coal-to-busbar efficiency. (RP261)



Fuel densification

In late 1972 AEC placed temporary operating restrictions on some power reactors after observing the pinching of some PWR fuel rods, which was

attributed to densification of the fuel pellets contained. AEC also required new conservative assumptions in licensing safety calculations, which led to temporary reductions in maximum operating power and other restrictions at a number of nuclear units. An EPRI study determined the structural characteristics and irradiation behavior controlling the densification of fuel pellets and developed procedures (subsequently used by NRC) for inferring this behavior from simple out-of-core tests. Dollar savings are impossible to quantify, but success in fabricating densification-resistant fuel assures the industry this is no longer a problem. (RP131)

Fuel performance evaluation

Because the reliability of nuclear fuel and the ability to predict fuel rod failure probability are so important, EPRI evaluated the ability of an empirical model to make such predictions based on mechanical interaction between the uranium dioxide fuel pellet

and its cladding. The EPRI study showed that such a model can predict failure probability in LWR fuel rods. The model permits the utility to optimize core power maneuvers to minimize both loss of plant output and number of failed rods. EPRI is now computerizing the logic of this analytic model for optimal use by site engineering and operating staffs to improve fuel reliability. Its importance is indicated by the $3–$5 million annual cost of replacement power due to reduced plant availability or capacity factor caused by fuel reliability problems. (RP509)

ENERGY CONVERSION

BWR blowdown

A major consideration in designing and licensing power reactors is providing sufficient cooling capability to keep fuel from overheating in the remote event of a LOCA. So it is essential to be able to predict the response of the system and fuel and to design accident-preventing or -limiting steps into the system. EPRI, NRC, and General Electric Co. sponsored engineering tests on BWR system performance under LOCA conditions. The tests showed a number of inherent cooling mechanisms are not taken into account in current licensing evaluation methods. The results from this project are being used to develop more accurate and realistic computer codes

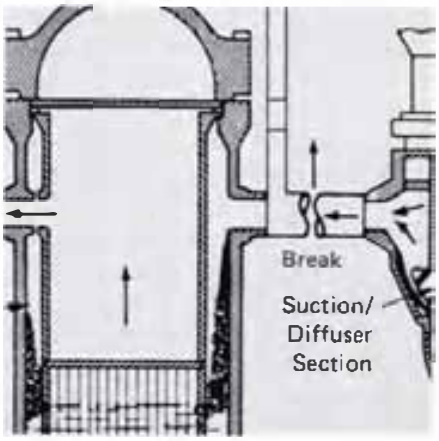
to improve BWR safety margins. A potential 1% increase in plant capacity would be worth $100,000–$600,000/plant-year. (RP288)

BWR torus

The capability of BWR pressure suppression systems to withstand sudden loads from hydrodynamic forces in the event of LOCA and relief-value discharge conditions has become a subject of concern. Using scale model experiments and mathematical and analytic techniques, EPRI has studied and quantified the pool-swell effects in the pressure suppression torus under such conditions. The test data were taken into account in an NRC regulatory decision permitting continued operation of a group of BWR units while assessment of the situation went on. EPRI has also developed a computer model to predict the motion of water in the pool during a blowdown. The cost of EPRI's effort to date has been estimated as being less than two days of downtime on a single BWR power plant. (RP693-1, RP693-2)

Steam-water mixing

Another LOCA research program pertains to the ability of a PWR system to accept the injection of emergency cooling water to keep the reactor core covered with the intact piping circuits. EPRI experiments and analyses of



steam-water mixing furnished data allowing more realistic analysis of steam-venting conditions, and has resulted in a reduction of 50–100°F in the maximum temperature calculated during a postulated LOCA when the ECCS goes into operation. Model work at 1/3-scale confirmed that plugging does not occur during core reflood. The data have been placed in the public domain, saving utilities many times the project cost. (RP294)

Decay heat

Afterheat following shutdown in a reactor due to fission product decay is an important parameter in LOCA and other safety evaluations. Experimental difficulties have often precluded making direct measurements of afterheat. EPRI has carried out measurements to establish it with high precision and accuracy. The low-error band of the data, together with other recent experimental and theoretical studies with which the data are in good agreement, will lead to reevaluation and possible lowering of currently accepted standards. This would have a significant impact on the safety analysis and licensing of nuclear plants. Each 1% uncertainty in decay heat results in a 1% decrease in maximum permissible power for each nuclear unit that has been derated for LOCA considerations, and each 1% reduction of the uncertainty band represents a potential saving of $100,000–$600,000 per unit per year. (RP392)

New computer codes

More and more, utilities need analytic capability to make structural and reactor fuel management analyses and operations safety evaluations—tasks for which the tools have not been widely available. EPRI has developed five analytic codes for use by utilities: ARMP, MEKIN, STEALTH, RELAP/E, and RETRAN. ARMP provides a fuel management and operations analysis capability. MEKIN is a computation program for analyzing reactor core transients in BWRs and PWRs. STEALTH analyzes such phenomena as seismic wave propagation, the BWR pressure-suppression system, residual stress from welding, and so on. RELAP/E is a new, improved calculation tool for "best estimate" analyses of ECCS performance in LOCA situations. RETRAN is used for calculation of reactor system transients. (RP118, RP307, RP342, RP811, RP889)

Tornado missile protection

Nuclear power plants are required to be safe against impact from tornado-borne debris, even debris of improbable weights and speeds. EPRI's tests with rocket-propelled objects driven at high speeds into simulated auxiliary building walls showed that 12-in reinforced concrete walls can safely withstand impact by utility poles, 3-in diameter steel pipes, and 1-in reinforcing bars; 18-in walls can also withstand being struck by 12-in pipe sections. These results prove that a

nuclear plant is safe in tornado conditions. It may also be reasonably assumed that the results contributed to NRC's decision to reduce minimum wall-thickness requirements to 20 in from 24 in for eight nuclear units under construction or awaiting construction permit. This means a potential significant cost saving for the affected buildings. (RP308, RP393, RP399, RP616)

Crack arrest data

The probability of cracks initiating from existing flaws in a reactor pressure vessel under normal and test conditions is extremely small. However, in a hypothetical accident, such as a LOCA, crack initiation is postulated for small flaws located in certain regions of the vessel and it is necessary to demonstrate that such a crack will stop growing before it traverses the reactor wall, maintaining vessel integrity. Theoretical and experimental studies on pressure vessel steels showed present regulatory rulings on crack arrest to be conservative and established improved confidence levels in the accepted curve for predicting crack arrest. The primary research benefit is minimizing the probability of extended outages for inspection or repair caused by uncertainty in calculations rather than by actual hazard. (RP303-1, RP303-2, RP499)

Steel fracture toughness

In 1972 AEC declared that additional research was required to demonstrate the adequacy of fracture toughness requirements for nuclear pressure vessel steel. EPRI tested more than 50 heats of steel from normal production lots to determine generic fracture toughness requirements for pressure vessel fabrication use. The results of the study show that present design practices are overly conservative. Thus the project averted potential forced outages due to regulatory action by

providing more accurate methods for characterizing flaws in pressure vessels. The reduction of forced outages represents a substantial saving to the utilities that could average from $250,000 to $300,000 per day per unit. The results have also been submitted to ASME. If adapted, they will help to limit the continuing increase in design and analysis requirements. (RP232, RP312, RP696)

Boiler feed pump improvement

Boiler feed pump failure is a major cause of power plant forced outage, costing an estimated $55 million a year in fossil-fired units larger than 600 MW. An EPRI survey revealed that many boiler feed pump failures result from axial imbalance or pump rotor instability. The impeller thrust on a worn pump may exceed the balance disc reaction on the original design. A simple modification of the balance disc in trials proved to rectify the disorder and prompted vendor adoption of the design change. Other problems were also identified in the survey, resulting in improvements that are estimated to be worth about $10 million a year in savings to the industry. The Salt River Project in Arizona anticipates yearly savings of some $2 million. TVA expects to save nearly $1 million a year in replacement power costs. Outlay for the EPRI survey was $26,000. (RP641)

Optimized solar energy system

As solar heating and cooling systems come into wider use, increasing fractions of central electric generating capacity will have only a standby or backup role. Yet the costs of that capacity will remain in the rate base. A computer program has been developed with the capability of determining optimal, or "preferred," solar heating and cooling systems for specific service areas, including the

utility costs of providing supplemental or backup service. The program permits analyses of system and subsystem sizing, various utility service costs, different rate structures, and shifts in utility load characteristics. To test the program, it was exercised with specific data from the service areas of 16 electric utilities. It is now being extended and documented so that the program and a user's guide can be made available to utilities later this year. (RP549, RP926)

ELECTRICAL SYSTEMS

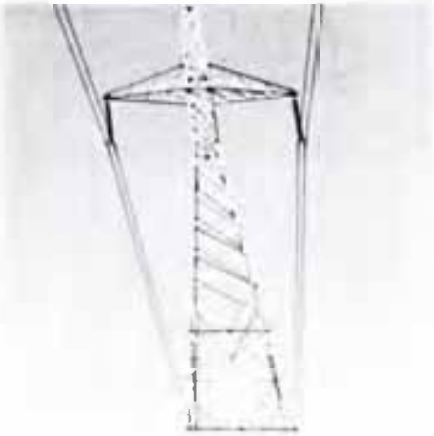
Ultrahigh voltage transmission

As systems expand, a point is reached where it becomes necessary to introduce a new voltage level. Historically, the new voltage has been approximately double the highest existing voltage on a system. Utilities with 500-kV and 765-kV systems began to consider a higher voltage in the 1100–1500-kV range that could serve the needs of both systems. Testing

conducted at Project UHV has demonstrated the engineering feasibility of constructing and operating transmission lines in this range. The *Transmission Line Reference Book, 345 kV and Above* was published in 1975, giving data and design rules for conductor selection, insulation requirements, and electric fields. At least three utilities are currently using the data to develop transmission alternatives for their future generation additions. (RP68)

HVDC transmission lines

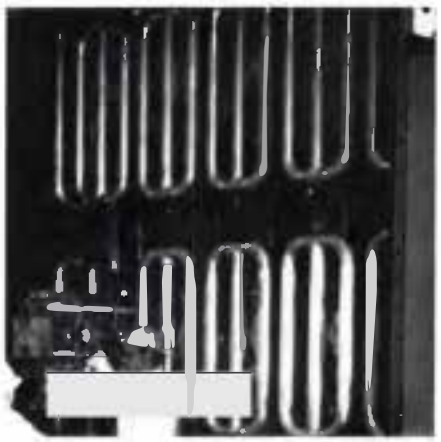
Successful operation of the Pacific Coast dc interties showed the advantage of dc transmission for certain special utility applications. Although a pattern of dc line costs has not yet been firmly established, the data devel-



oped through this project will reduce the engineering man-hours required for the design of future dc projects. The Bonneville Power Administration cooperated with EPRI to complete research on design criteria for circuits rated to ±600 kV. Results of this project were published in the *Transmission Line Reference Book, HVDC to ± 600 kV*. The data have been used in planning or constructing lines across Minnesota, Utah, and Arizona. Publication and use of these data will lead to confidence in the selection of dc transmission options to enhance system stability and achieve economic benefits in long-distance, bulk power transmission. (RP104)

Prototype dc link

In future years HVDC transmission is expected to play an important role in power infeeds into the city areas. Its inherent advantages include lower cost and ease of high-capacity cable transmission, no increase in short-circuit current at the points of con-



nection to the ac system, and controlled power infeed. But power infeed cannot be installed in city areas without compacting the dc terminals. Compact converter technology—in its entirety, or in part—is needed today. One EPRI project involves research, development, design, manufacture, and installation of a 100-kV, 100-MW (with 400-kV insulation) link with compact terminals at the Astoria Substation of the Consolidated Edison Co. When energized in 1978, this development will be applicable, jointly or separately, to converter ratings up to ±400 kV, 1000–2000 MW. (RP213)

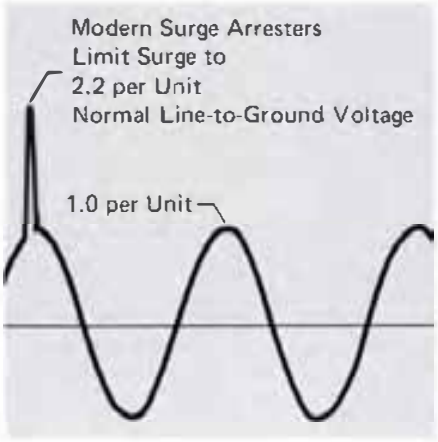
Calibration of CCVTs

Coupling capacitor voltage transformers (CCVTs) are used in bulk power substations to sense voltages needed for metering and control. Periodic calibration of the voltage and current sensors is necessary to ensure accurate power-flow metering and

reliable system protection and control. Calibration errors in these devices may be eight times the allowable, and aging of the device may cause drift in the calibration from year to year. A prototype mobile unit suitable for use in field calibration of CCVTs has been successfully developed, constructed, and field tested. Based on field experience, the design is being optimized. The field trials of the calibration system have verified the need to calibrate the voltage ratio and phase angle of CCVTs on installation and periodically thereafter. (RP134)

Varistors for surge arresters

Power transformers and other substation equipment, as well as overhead lines, must be built to withstand overvoltages caused by lightning, switching surges, and ferroresonance. This extra insulation is costly and adds to the size and weight of the equipment. Two projects were initiated by EPRI to develop improved metal oxide surge arresters for overvoltage protection. Two contractors have



developed devices that could be used to produce surge arresters with better protective characteristics than the present gap-type arresters. Work completed at this time will make these devices available for other applications, such as fault current limiters, dc breakers, and series capacitor protection. One utility is planning to test a series capacitor scheme using ZnO arresters. (RP657)

Controlling decay in wood poles

It is estimated that 50% of the four million wood poles sold annually in the United States are replacements for existing poles that are considered unsafe due to groundline decay. A research effort was undertaken to better understand the decay mechanism in wood poles and to determine

the most effective and environmentally safe method of controlling decay with fumigants. Internal decay in Douglas fir poles can now be arrested with one of three new volatile chemical fumigants. As liquids poured into holes drilled into the pole near the groundline, these fumigants vaporize and move deep into the pole, traveling both upward and downward from the point of application. They have been demonstrated effective for six years or more in controlling internal pole decay. One of the fumigants is already in use by companies offering pole treatment services. (RP212)

Splice for extruded insulation

Tape-wrapped splices have long been used very successfully for oil-paper cables, and a polymeric tape wrap was the first means tested to splice the newly developed solid dielectric cables rated 138 kV. In spite of the historical reliability of taped splices on oil-paper cables, their counterparts on extruded dielectric cables have performed quite

poorly. The premolded splice that has been developed can be tested in the factory before shipment and should be more reliable. The new splice allows for shrink-back of the cable insulation, requires only nominal skills that are easily taught and learned, and needs significantly less installation time. The availability of a more reliable splice is expected to promote the use of the more efficient and potentially more economical extruded dielectric cables. (RP7815)

Polymer concrete insulation

Porcelain has long been the basic outdoor insulating material used by the industry. There have been recurring shortages of porcelain during peak construction periods, with deliveries delayed as long as two years. The production of porcelain is also an energy-intensive process due to the high-temperature firing required for porcelain products. A project was

initiated to investigate the feasibility of using a cast concrete impregnated with a polymer compound as an alternative to porcelain. The new polymer concrete (now designated Polysil) has twice the dielectric strength of porcelain and one-half the dielectric constant. Polysil has passed all electrical and weathering tests available in the laboratory. Present production estimates are approximately 50% of porcelain costs. (RP480)

ENVIRONMENT, ENERGY MANAGEMENT, AND ENERGY R&D ANALYSIS

Fossil fuel combustion and health

Air quality standards in the U.S., established in 1971, were based largely on inadequate data. Recognizing the need for improved understanding of air pollutant effects so that a rational, cost-effective control strategy can be planned, EPRI is analyzing much of the data that support today's standards and the information developed since 1971. A reassessment of a

Sulfur Oxides: Cur

keywords
Sulfur Oxides
Health Effects
Air Pollution

portion of EPA's Community Health Evaluation Surveillance System (CHESS) results, for instance, indicates that the original interpretation of the findings may be incorrect. EPRI's analyses have paid special attention to data relating to sulfur oxides, nitrogen oxides, and particulates, and their effects on health. The results of these studies should provide a more realistic base for revised air quality standards. (RP681, RP809)

Effects of electric fields

As the voltage in transmission lines has increased, so has public concern over the possible harmful effects that electric fields generated by these lines may have on exposed plant and animal life. EPRI is funding $2 million in research to determine those effects.

A comprehensive review of the results of previous research has been compiled and a study of effects on cardiac pacemakers is nearing completion. Several projects are under way to determine effects on large animals, mice, chick embryos, honeybees, and plants and to assess the possible effects on humans. So far, no adverse effects have been found. The facts developed by this intensive investigation will be useful to utilities in continuing to design, construct, and operate systems with due regard for public health and safety and for environmental integrity. (RP129, RP381, RP581, RP679)

Uranium resources and prices

EPRI analyses of the data supplied by AEC and ERDA on uranium reserves and resources indicated serious inadequacies, which led to new estimates published by EPRI. For years, uranium prices did not appear on the industry supply curve; information on discoveries was incomplete and slow in being reported. Three EPRI

studies have provided a description of the strengths and weaknesses of AEC–ERDA data, an analysis beyond that of AEC and ERDA on domestic exploration efforts and results, and an economic interpretation of uranium costs and prices and their significance in forecastings. These studies produced information that helps determine whether uranium resources can support planned LWR expansion and enables a more accurate assessment of uranium resources. (RP489, RP490, RP666)

Energy assessment models

Energy models are essential in EPRI's R&D planning. They also provide insights into alternative futures for the utility industry and can present the industry's perspective to government for consideration in forming public policy. EPRI is developing assessment models and applying energy-economic models to evaluate the cost-benefit relationships of alternative energy technologies. Models have been used to explore such issues as the economic consequences of a nuclear moratorium and the payoffs from a vigorous synthetic fuels program. EPRI also has established the Energy Modeling Forum, bringing together energy model developers and users from private industry, public agencies, and universities to improve the understanding and use of models. (RP263, RP442, RP652, RP873, RP874, RP1014)

Peter Bradford: Perspectives on Energy

Commissioner Peter A. Bradford brings to EPRI's Advisory Council energy perspectives gained through experience with the consumer movement, environmental matters, and energy policy planning.

▫ An EPRI interview

When you talk about a diversified energy strategy, you're talking, in part, about the ability of the electric utility industry to use a variety of basic fuels to provide energy for consumers," explains Peter A. Bradford, a utility commissioner in the State of Maine, a member of EPRI's Advisory Council, and, as of July 13, a nominee to the Nuclear Regulatory commission.

When Bradford talks about a diversified energy strategy, he's talking about his view of an optimal energy scenario for the future—a scenario that will ensure security and maximize freedom of choice.

"The real key to energy security is maximizing your alternatives so that if any one source is cut off or turns out to be economically unfeasible, you won't have too many of your eggs in that basket," says Bradford, a 35-year-old attorney who served as one of "Nader's Raiders" and who is today one of three members of the Maine Public Utilities Commission. "It's easy to imagine an Arab oil minister turning off a pipeline, but there's another kind of embargo—discovering that a particular energy source is too dangerous to use or that it pollutes the air so badly it can't be used. What's really involved is coming up with a mixture of technologies to maximize freedom of choice. That means coal, nuclear, hydro, and oil, plus whatever else you can sensibly use. That way, you have a mixture of plants in a mixture of locations with an appropriate mixture of transmission lines, and no one contingency will black you out."

Peter Bradford discussed his views of the nation's energy future during an interview in his office in Augusta, the capital of Maine. It was April 20, the day President Carter was to unveil his energy proposals to a joint session of Congress. Bradford explained his belief that the government's role in dealing with the energy problem should be to ensure freedom of choice at national, state, regional, and individual levels.

For example, although most government energy programs in recent years

"I think the federal government may have been too hasty in its emphasis on conversion from oil to coal."

have emphasized reduced U.S. consumption of foreign oil, Bradford believes that regional freedom to use this power source should be maintained as long as it is economically feasible.

"I think the federal government may have been too hasty in its emphasis on conversion from oil to coal, at least as far as this region is concerned," the commissioner says. "We're about as far as you can get from the coal fields. We shouldn't rely overly on foreign oil, of course, but I don't think it's a wise federal policy to rule it out altogether as a source of fuel for power plants."

Bradford stipulates that plants allowed to burn oil should have standby plans, such as the capability of converting to coal or another fuel. And he says the regions served by those plants should have the capability of getting along without them for a limited period of time. But as long as oil remains economically feasible for the region involved, he contends that it should not be altogether discarded as a power source.

In the diversified energy strategy he sees for the future, Bradford describes the electric utility industry as playing "a critical swing role" because of its ability to convert a variety of basic fuels into energy for a range of uses.

"Electric energy production is the only way we can rely on uranium as a fuel source, because you and I can't use uranium in our homes. In New England, it's the only way we now use coal, because New Englanders don't burn coal as fuel any more. And it diversifies our reliance on oil, in the sense that power plants use No. 6 oil, while we use No. 2 oil to heat our homes."

In this scenario Bradford attributes a critical role to electric energy research and development. "It's inevitably a part of trying to expand alternatives," he says, "and I assume that EPRI is going to be very much in the forefront of that effort."

Peter Bradford is one of seven utility regulators who sit on EPRI's Advisory Council. He brings to that role a background of experience in the consumer movement, environmental matters, and energy policy planning on a state level.

A 1968 graduate of Yale Law School, Bradford was one of the original members of Ralph Nader's consumer action group in Washington, D.C., working that summer on what he describes as "a study of the Federal Trade Commission's failure to adequately discharge its duties." After that he joined the staff of then Governor Kenneth Curtis of Maine, acting as an adviser on oil, power, and environmental affairs and assisting in the preparation and drafting of Maine's landmark laws on oil handling and industrial site selection.

Since 1971 he has served on the Maine Public Utilities Commission; he was chairman for 11 months. One might think, given his background, that his perspective in this role would be entirely consumer-oriented. Indeed, he admits that he was appointed to the commission "specifically as the result of consumer groups in Maine requesting that the governor find someone with a perspective on consumer problems."

However, Bradford resists the label of consumer advocate with respect to his position as a state utility regulator.

"I don't think that's what I'm here to do under the law or the theory of regulatory commissions," he explains. "Commissioners are supposed to bring the best judgment they can to the solving of problems within the legal framework they are set up to work under. And there's just no way that you can logically always adhere to a consumer perspective or an environmental perspective or a utility perspective and be doing the job you're supposed to do."

He uses nuclear power as an example of the inconsistencies that can be involved. "At least one environmental perspective says you should be opposed to nuclear power, and there would be a consumer perspective, at least on the basis of Maine Yankee's operating record, that would lead you to be for it. The two perspectives may merge somewhere down the road, but in the short run at

least, they aren't consistent. So I don't think it's a good idea for a commissioner to try to be an advocate of anything other than common sense and good, independent judgment."

Common sense, to Bradford, implies a fair measure of skepticism, an attribute he claims he acquired during his association with Ralph Nader. "Before that I was inclined to believe that things worked more or less the way one learns they work in high school and in college," he recalls, smiling. Working with Nader impressed on Bradford "the importance of proceeding with real concern, with thoroughness, and with a willingness to work terribly hard." It also made him realize, he says, that "there was a sound basis for the things Ralph was saying about the ways that regulated industries regulated their regulators."

Peter Bradford is the type of independent thinker who can be intimately involved in a situation and yet be able to assess it with the calm impartiality of a casual observer. His quiet, easy demeanor is deceptive. Bradford can dissect a problem with the precision of a surgeon and articulate it with the directness and force of a trial lawyer.

He reveals all these qualities—skepticism, directness, independent judgment—when he discusses one of his primary concerns, the adequacy of state regulation of utilities. He believes this subject to be of critical importance to the electric utility industry, and although he sits on a utility commission himself, he does not hesitate to express his sentiments in frank terms.

"Utility regulation in Maine today is both a hoax and a crisis," Bradford charged during an address at a local college last year. In his speech he claimed that the utility commission was understaffed, overworked, and inadequately funded. It was therefore unable to responsibly regulate the large, well-funded industries entrusted to it. His pronouncements drew instant response from the press and the public in Maine and were instrumental in spurring remedial action.

When Peter Bradford discusses utility regulation, he doesn't limit his comments to the State of Maine. In fact, he believes that utility regulation has been uniformly inadequate in the recent past and that regulated industries, including the electric utility industry, suffer today from a credibility problem, partly as a result of association with what he calls the dwarf commissions of the 1960s.

"Most industry executives have begun to realize that their own credibility is very closely tied to the credibility of the government agencies that regulate them," he explained. "A utility has no credibility in saying that it needs a rate increase, for example, if it can be shown that the public utility commission that grants the increase does not exercise informed judgment in doing so. Many of the industry's other problems would be diminished if the public is prepared to trust the regulatory and governmental processes that affect the industry's credibility."

According to Bradford, the problem is that the public has been unwilling to give that trust. He claims this reluctance stems from a period in the 1960s when regulation was not under scrutiny and commissioners had terms much longer than their vision. Appointments to the commissions were "political in the very worst sense," Bradford explained, involving "people who knew nothing about the industries they were regulating and who weren't under any public pressure to learn."

These are the "dwarf" commissions that Bradford speaks about. He says that "when the crunch came, they lacked the staff, the budget, and the sophistication to deal independently with the problems that arose."

The "crunch" was the combined effects of inflation, consumerism, and the 1973–1974 Arab oil embargo. It resulted in escalating fuel costs that were immediately passed on to consumers through fuel adjustment clauses. Suddenly the public was complacent no longer. Commissions came under fire,

"Commissioners are supposed to bring the best judgment they can to the solving of problems within the legal framework."

and according to Bradford, "governors couldn't get away with the kinds of appointments they were making before. They started appointing professionals with some kind of knowledge of utility regulation: attorneys, economists, environmentalists, consumer representatives. The shift within the state commissions was dramatic."

As a result, Bradford believes that public faith in the independence and honesty of the regulatory processes is slowly being rebuilt on sounder foundations. He believes that as this happens, the credibility of the regulated industries—including the electric power industry—will improve as well. "Then when a government agency says that a rate increase or an energy policy is necessary, the public will be more willing to believe that it really is."

Similarly, Bradford contends that as the research funded by the electric utility industry is found credible by government bodies working on energy issues, that credibility will be transferred to EPRI and through it to the industry.

"Five years ago the electric industry was sharply criticized for not doing enough R&D," he says. "It was left to the equipment manufacturers, and it always turned out that any given power company was spending far more on advertising than on any kind of R&D. EPRI should remove that negative factor and fill the gap."

Will EPRI's research results be accepted as credible by a public that looks on the Institute as an industry-funded organization?

"That depends on the format," Bradford comments. "In many cases the credibility won't come until some other group has also relied on EPRI's research conclusions and has found them to be valid. For example, if EPRI officials are invited to testify before Congress and the material they present is accurate and stands up under scrutiny by staffs that have some knowledge of the field, that will build up a sort of institutional credibility. Unfortunately, the climate today is such that people go by labels, and if something comes from industry, it loses credibility. The process of reversing that will depend partly on the integrity of EPRI's research and partly on a more general process by which credibility is transferred to EPRI through other groups."

One of Bradford's key concerns in electric utility research is what he calls capacity conservation, which he explains as "the whole business of rate redesigning, making better use of the capacities that the utilities have now."

He sees a clear potential for it. "It's been reflected in Bell System's prices for years, and if you can make a very cheap phone call after 11 p.m., then by the same theory you also ought to be able to purchase relatively cheap electricity after 11 p.m.

"If it works with the telephone industry, which has the same capital-intensive pattern and need to meet peak demand as the electric utility industry, there's no reason it can't work with the electric industry as well."

Bradford is a member of the EPRI Advisory Council's Power Sources and Uses Committee, which studies the efficient use of nuclear and fossil fuels and other power sources. The use of nuclear power is an issue about which he admits ambivalent feelings.

"If I had nothing to go on but the existing track records of the nuclear plants now serving the State of Maine, I would be—I guess—a gung-ho nuclear advocate. As a regulator, I can't responsibly deny that it has been the best possible source of power in Maine in the last two or three years," he admits.

His reservations stem, he says, from questions that have yet to be answered to his satisfaction. "What happens if we run out of naturally occurring uranium? If we do, do we use reprocessed fuel and plutonium? If we don't, what will we do about waste storage?" Until these questions are answered by both government and industry, Bradford says he would find it very hard to approve a nuclear plant if an application were brought

"It doesn't serve anyone's interest to have important decisions delayed beyond the minimum time necessary to analyze the data and reach a fair result."

before him.

"It just doesn't make sense to me to ask a state agency to say that the public needs a facility whose sources of fuel and whose waste disposal are so uncertain 10 or 15 years down the road. If you don't know that reprocessed fuel is going to be a possibility, and if you don't know what you're going to do with the spent fuel if it isn't, it's pretty hard to vote for the power source, even acknowledging its clear economic and environmental benefits in New England compared with those of coal."

Utility regulators are often criticized by the industries they regulate for unreasonable delay in approving plant applications and rate changes. Bradford can see both sides of the issue.

"This whole syndrome of regulatory lag is a two-way street," he says. "Within limits, regulatory lag is one of the great incentives to efficiency. Utilities can make money by achieving savings between rate cases. On the other hand, it can't be denied that regulatory lag is a problem and that it doesn't serve anyone's interest to have important decisions delayed beyond the minimum time necessary to analyze the data and reach a fair result. For a big rate case or a nuclear power plant, there's going to be a period of months necessary to reach a decision, but it shouldn't ever stretch out into years."

On this subject Bradford speaks from the perspective of one associated on the receiving end with an example of regulatory delay at its worst. He calls it the Machiasport incident.

In 1968 the State of Maine applied to the federal Foreign Trade Zones Board for the creation of a foreign trade zone in the area of Machiasport, a job-poor coastal fishing village of some 800 inhabitants. The zone would have enabled a group of entrepreneurs to build an oil refinery to be run on low-cost imported oil. The New England governors supported the project because it would have provided a way for their states to secure home heating oil at prices lower than prevailing domestic rates. Maine was enthusiastic because the prospect of a new industry promised economic revitalization for a depressed area. The application was filed in 1968; two years later it still lay untouched. The refinery was never built and New England never got its oil.

Bradford was involved behind the scenes in the incident through his role as an aide on oil and power issues to Maine's Governor Kenneth Curtis. He chronicles the Machiasport incident in a book published in 1975 by Harper's Magazine Press. Titled *Fragile Structures: A Story of Oil Refineries, National Security, and the Coast of Maine*, the book describes how a group of diverse interests were able to block action on the Maine application and destroy the chances of building the refinery. The *New York Times* describes the book as "a thoroughgoing account of how energy policy is made—not just through rational debate among competing interest groups . . . but through back-door and side-door pressures as well."

Fragile Structures describes an era in energy policy making that Bradford feels industries such as the electric power industry should have studied more closely than they actually did. "Anybody looking at U.S. oil policy in a serious way in 1968–1969 had to be very alarmed about it," he says, "and the industries that relate to it, such as the electric power industry, would have been better off knowing a little more, I think, about developments with regard to oil. The timing makes such a difference. Things learned in 1974 might have been much more valuable if they had been learned in 1973 or 1972."

Bradford feels the same way about national energy policy. "Timing," he says, "is a critical ingredient. One of the problems today is that so many years were lost during which no policy decisions were made that you get backed further and further into a corner and your solutions have to be more and more drastic.

"To some extent the president is in a box because for at least 10 or 12 years

"What's really involved is coming up with a mixture of technologies to maximize freedom of choice."

energy policy was neglected—to be more accurate, 30 or 35 years. In terms of changes in the nation's high gasoline consumption pattern, a decision to tax automobiles moderated in 1969 or 1970 would have brought about the same results as a very high gasoline tax imposed today, and it would have done so much more painlessly."

Although Bradford is optimistic about the current administration's energy proposals, he is uneasy in the sense that "I can't make all the pieces consistent with one another." One of these pieces is the possible effect of a proposed gasoline tax on the poor.

"In the short run, it looks as though this combination of energy policies, including lowered energy growth, is going to hit poor rural states very hard, especially poor rural states with no indigenous energy resources other than falling water.

"Maine people, for example, drive long distances to work. By and large they do it in old cars that are not very energy-efficient. The use of a tax—especially a tax suddenly imposed—is going to mean that an awful lot of the fuel saving will come right out of the hide of the rural poor. They're just not going to be able to continue using their automobiles the way they always have. That's a very sharp diminution in the quality of life at the lower end of the social scale where the quality wasn't very high to start with."

Bradford explained that he would much prefer to see the same goals met through the pricing of automobiles. "Then the energy-consuming machinery would change, rather than an abrupt change in the lifestyle of people in a state like Maine."

Although Bradford feels that energy policy should include consideration of social issues, he does not usually favor using energy prices to achieve income redistribution. He is not, for example, an advocate of lifeline electricity rates for the poor and the elderly, despite a year-long experiment with the concept in Maine.

"When the legislators who devised the bill came to me about it, I asked them to convert it into some sort of time-of-day experiment," Bradford explained. "My theory was that the lifeline experiment really wasn't going to tell us much. I contended that if you hold rates down to three cents per kilowatthour for a specified class of people and offer them that rate versus a higher rate, they will take the lower rate. You will learn that and not much else."

Although Bradford is "all for making sure that elderly people and poor people have enough money to pay their electric bills," he takes the "fairly conventional view that it's better done through the normal system of assistance for payments, whether it's social security, unemployment compensation, or welfare. It seems to me," he says "that this is the way to do it rather than to hold the electric rates down artificially."

Bradford chuckles when he recalls that he did make one significant contribution to the legislation mandating Maine's lifeline experiment.

"Originally the bill provided that the only qualification for the lifeline rate was being over 62 years of age," he explained. "I did point out that Nelson Rockefeller's summer home was in Maine and that he did not need that kind of assistance." Bradford explained that the legislation was changed to include an income standard.

Peter Bradford's term on the Maine Public Utilities Commission will end in December of this year. What lies ahead for him is uncertain, he says.

"I suppose if I'm ever going to practice law I should do it for at least a few months," he laughs. "But if I don't, I'd like to do some more writing, in the short run at least."

What about the long run? What about elective office? At the time of this interview, Bradford made no comment on the one and dismissed the other. But even his short-run plans for writing or law practice, not to mention his remaining months on the state commission, were put up in the air by the White House announcement on July 13 of his nomination by President Carter to a position on the Nuclear Regulatory Commission.

The nomination must be seen as an endorsement of Bradford's performance in energy affairs. Subject to his confirmation by the Senate, then, it appears that Bradford will move from the nation's wings to spend his next five years on its center stage.

At the Institute

Board Approves $40 Million in Research

The EPRI Board of Directors approved $40 million in electric energy research for 50 new projects and 25 previously authorized projects at a meeting in Washington, D.C., on May 5.

In fossil fuel research, the directors approved a $3 million funding increase to continue operating a pilot plant at Wilsonville, Alabama, that produces clean solid fuels from coal. The project is also being funded by ERDA and Southern Company Services, Inc., of Birmingham, Alabama.

In the area of new electric energy technologies, the Board approved a joint project with ERDA to develop preliminary engineering designs for compressed air storage and underground pumped hydro storage systems for use by utilities. Another key project approved by the Board will develop information on the costs of heliostats (mirrors) that may be used at solar-thermal power plants. Recent studies indicate that heliostats are a key cost item in central-receiver solar plants.

A series of studies were approved for electrical systems research to determine the effect of broken conductors on transmission lines. The tests will be performed on seven miles of transmission line scheduled for dismantling by Wisconsin Power and Light Co. Also approved was a joint project with the National Bureau of Standards to develop a screening program to determine the suitability of using certain polymer materials for high-voltage underground transmission cables.

The Board established budgetary guidelines for EPRI for 1979–1982, which provide for more than $1 billion in electric energy research and development. A 1978 research and development budget of $193 million was approved.

Another significant action was the interim appointment to the Board of Floyd W. Lewis, president of Middle South Utilities. Lewis, who will serve until the 1978 Annual Meeting of Members, is filling the vacancy created by the death of Clyde A. Lilly, Jr., president of Southern Company Services, Inc.

The Board elected Frank M. Warren as its chairman and Aubrey J. Wagner as vice chairman. Warren is chairman of the board and chief executive officer of Portland General Electric Co. (Oregon). He succeeds Shearon Harris, chairman of the board of Carolina Power & Light Co. Wagner is chairman of the Tennessee Valley Authority.

At the annual meeting of EPRI members the day before the Board meeting, John J. Bugas, president of Colorado Ute Electric Association and Thomas J. Galligan, Jr., president of Boston Edison Co., were elected to the EPRI Board for terms of four years each.

Lewis

Warren

Wagner

Bugas

Galligan

Former EPRI Chairman Honored

Leaders of the nation's electric utility industry met on May 5 in Washington, D.C., to honor James E. Watson, who recently retired from the Tennessee Valley Authority (TVA). Watson had served with TVA since 1936 and was manager of power from 1969 to 1976—a position that placed him in charge of the nation's largest electric system. He also served as senior adviser, power; director of power marketing; and chief, power contracts branch.

Watson was a member of the Federal Power Commission's Southeast Regional Advisory Committee on the National Power Survey and a member of the National Electric Reliability Council, and he was chairman of EPRI's Board of Directors from 1973 to 1975.

Watson

Cable Boring Technology Workshops

Two EPRI workshops in the field of distribution cable boring technology were held in Dallas and Atlanta. EPRI is planning to sponsor research in this area and the April workshops were organized to obtain information on the state of the art.

Boring is one of the methods used to install underground distribution conduits and directly buried cables; it is an alternative to the more commonly used methods of trenching-backfill and plowing.

"Electric utilities have used boring for years to install underground facilities, especially where other methods are not permitted," says EPRI's Dick Steiner, citing its use under railroads and thoroughfares as a key example.

Steiner, manager of the EPRI Distribution Program, notes that the amount of underground distribution line installation being done by boring still represents only about 1% or 2% of underground distribution line construction. But he also says that if boring methods and equipment were improved, applications could be significantly increased. "This method could prove particularly advantageous for future cable replacement," he states.

Three main recommendations were made by the workshop participants: first, EPRI should investigate the guidance system for a mechanical mole—developed some years ago by the Bell Laboratories—to determine if it could be applied to electric distribution boring; second, EPRI should proceed with research to develop improved equipment for small bores; third, EPRI should consider a parallel research effort to develop a system for detecting and locating subsurface obstructions to boring and trenching.

Fast Breeder Called Energy Insurance Policy

The cost to the nation of deferring the fast breeder reactor (FBR) will range from $100 billion to as much as $3.5 trillion over the next 75 years, according to René H. Malès, director of the EPRI Energy Analysis and Environment Division, responding to the recently released Ford-Mitre study on nuclear power issues and choices.

Addressing the Nuclear Regulation Subcommittee of the Senate Committee on Environment and Public Works in Washington, D.C., on April 28, Malès referred to the breeder as a national energy insurance policy. "If our other known major energy resources, coal, oil and gas, and uranium, prove to be adequate, the benefits of the breeder are still significant. But if some of these energy resources fall short of expectations, deferment of the breeder could cost us dearly."

Malès said that if all three major resources proved to be in short supply, financial consequences of FBR deferment could go as high as $3.5 trillion. That would amount to a 5.7% average annual reduction in gross national product between now and the year 2050, according to the EPRI division director.

Malès told the subcommittee that future electricity prices would rise substantially if the amount of economically recoverable uranium is limited. "However, timely introduction of the breeder can significantly reduce the size of that increase in electricity cost to the consumer. Delays in breeder development could increase already high electricity prices in the year 2010 by nearly 100%, depending on future constraints of the major energy resources," he stated.

Yeager to Succeed Hill

Kurt Yeager will succeed George Hill as director of the EPRI Fossil Fuel Power Plants Department this September, according to an announcement by Richard Balzhiser, director of the Fossil Fuel and Advanced Systems Division. Hill will take the Envirotech Chair at the University of Utah as a professor in the Chemical Engineering Department.

Prior to his new assignment, Yeager was manager of EPRI's Air Quality Control Program. Donald Teixeira, formerly a project manager in the Air Quality Control Program, is replacing Yeager as program manager.

Yeager Hill

Teixeira

Hill joined EPRI in 1973 after 15 months as the director of the Office of Coal Research, U.S. Department of the Interior. Before that, he was on the faculty of the University of Utah for 26 years.

Yeager joined EPRI in 1974 after serving as director of Energy R&D Planning for the U.S. Environmental Protection Agency's Office of Research.

New Nuclear Policy Could Be Counterproductive

Proposals aimed at preventing nuclear weapons proliferation by not recycling nuclear fuel could be counterproductive and could increase the potential for spreading nuclear weapons rather than limiting it, said EPRI President Chauncey Starr.

In a luncheon address at the American Power Conference on April 19, Starr declared that "it is a disservice to the people of the U.S. and of the world to create the illusion that by putting restrictions on civilian nuclear power we have somehow solved the proliferation problem.

"In the Non-Proliferation Treaty, which 105 other nations signed at the urging of the U.S., we agreed to make available the benefits of peaceful nuclear power through international cooperation in return for a pledge of abstention from making nuclear weapons. That this policy has worked may be seen from the fact that almost any nation with the resources to afford a viable military establishment could certainly afford a nuclear weapon, yet only one—not a signer of the treaty—has chosen to do so."

The new U.S. policy, reversing a quarter century of U.S. strategy, will inevitably be seen abroad as a unilateral reinterpretation of our commitments under that treaty, Starr said. But because other nations cannot afford to make wasteful use or less than optimum use of their energy resources, even if the U.S. does so, those nations will be driven to develop or to buy from other sources their own reprocessing plants and breeder reactors.

"Thus it is clear," Starr stated, "that the proposed administration policy would be counterproductive by creating resource conflicts, removing faith in the U.S. umbrella to protect the welfare of its allies, and stimulating the expansion of indigenous nuclear capabilities abroad, including enrichment and reprocessing."

Spokesmen for a number of nations have indicated that this is an already developing international response. The EPRI president reported that at a meeting in New York last March, each spokesman declared that nuclear power is not a possible option but an indispensable necessity for his nation: "A French spokesman said his country is not even studying the option of not reprocessing spent civilian nuclear fuel and declared that France will provide and guarantee fuel cycle services to developing countries without strings attached." Starr also said that a West German remarked that U.S. denial of reprocessing or breeder technology would create greater pressure on others to move ahead faster with domestic reprocessing and breeder programs. At the same time, a Japanese said his country's confidence in dealing with the U.S. appears to have been shaken, according to Starr.

The EPRI president further pointed out that commercial nuclear power is only one of eight different ways available today, with widely known technology, to produce weapons material. Of the eight, it is the most expensive, takes longest to install and begin yielding material, and requires the highest level of support technology and the broadest base of support industry. "It is, therefore, the least likely route to be chosen should a government decide to establish its own capability to make weapons," said Starr.

Who would benefit from the new administration's policy? "The oil exporting nations, of course," said Starr, "and those nations that are continuing to develop all their nuclear power options without restriction."

EPRI Reports Available for Purchase

Technical reports describing research projects sponsored by EPRI can be purchased through the Research Reports Center (RRC) of Palo Alto, California.

All reports, however, will continue to be sent gratis to EPRI member utilities, utility industry associations, national, state, and local government agencies, and foreign organizations with whom EPRI has a legal agreement for the exchange of information.

More than 400 EPRI reports are available through RRC covering R&D on electric power production from nuclear sources, fossil fuels, and advanced systems; electric power transmission and distribution; and a range of electric energy and environmental concerns.

Lists and prices of EPRI technical reports can be obtained through Research Reports Center, P.O. Box 10090, Palo Alto, California 94303; (415) 366-5432.

Fusion Seminar Planned

A three-day executive seminar on fusion is planned by EPRI and ERDA for October 11, 12, and 13 at the Sheraton-Palace Hotel in San Francisco. The purpose of the seminar is to provide information for the utility industry that will help in assessing its role in fusion development.

The presentations will emphasize the status and potential applications of fusion power rather than the technical aspects of its development. According to Steve Nichols, seminar coordinator, enrollment will be limited.

Additional information can be obtained from Steve Nichols, Assistant Professor, Mechanical Engineering Department, University of Texas, Austin, Texas 78712; (512) 471-4585.

New Insulating Oils Meeting

General Electric Co., which is developing new insulating oils under EPRI contract, reported on its research to representatives from major U.S. oil companies at an April meeting.

Westinghouse Electric Corp. and McGraw-Edison Co. are also conducting research in this area for EPRI.

Ed Norton, a project manager in the EPRI Electrical Systems Division, explains that the electric utilities' supplies of naphthenic-based oils are vanishing rapidly and that alternative oils must be developed for transformers, circuit breakers, and other types of electrical equipment.

"Lubrication oils are made from the same distillation fraction as transformer oils. The same refining equipment, therefore, may someday be used for both industries," Norton says.

EPRI research is identifying the refining processes and the types of crude oils that have potential for utility applications.

EPRI President Chauncey Starr (left) welcomes T. K. Sloat of Westinghouse Electric Corp. (right) and Earl Morrison from the Department of Water & Power, City of Los Angeles, prior to a recent EPRI meeting on new insulating oils for electric utilities.

Project Highlights

Report Questions Air Pollution Health Effects Data

An EPRI report released early in May raises questions concerning EPA conclusions that there is a link between occurrence of asthma attacks and particulate and sulfate levels in air (EA-450).

Working under an EPRI contract, the San Rafael, California, firm of Greenfield, Attaway & Tyler reanalyzed data from a 1974 EPA report on this subject. That report was based on a study conducted by EPA in the greater New York City area during 1970 and 1971. The EPRI report does not question the fact that high levels of air pollution can produce adverse health effects. Instead, it simply concludes that the EPA data are inadequate to support any contention that there was or was not an association between the incidence of asthma attacks and the air pollution concentrations measured, which were in the normal range for that area.

During the fall of 1970 and winter and spring of 1971, EPA began a series of epidemiological studies known as the Community Health Evaluation Surveillance System (CHESS). They were carried out at several locations, including the greater New York City area. These studies generally involved the short-term impact of environmental agents, including air pollution, on certain health indicators, such as the daily occurrence of asthma attacks.

Since completion of the studies, many questions have been raised in the scientific community on the results of the study and their interpretation. Recently, a subcommittee of the U.S. House of Representatives Committee on Science and Technology, chaired by G. E. Brown, Jr., issued an investigative report that criticized all the reported CHESS studies. For one specific CHESS study (the one dealing with asthma), the EPRI report confirms the conclusions of the so-called Brown report.

"But in all fairness, any judgments or policy decisions based on the CHESS interpretations, as a whole, should await the results of the detailed reanalysis efforts now under way," says Cyril Comar, director of the EPRI Environmental Assessment Department.

Although CHESS data were not used in setting emission standards, Comar states that the data are being widely quoted in support of regulatory and standards action.

"For the first time, the EPRI report presents the original CHESS data, which were not available in the published literature, so that anyone can examine them," states Comar. In addition, Comar says the EPRI report provides biostatistical methods that may be useful to researchers in future epidemiological research.

As part of its overall research program, EPRI has been sponsoring a number of studies evaluating the possible health effects from fossil fuel combustion. The report released in May represents the second EPRI evaluation of health effects of air pollution. The first report, published in January of this year, deals with sulfur compounds. It emphasizes the inadequacy of existing data and describes the research needed for making rational decisions on sulfur emission standards as well as for developing sulfur emission control technologies.

EPRI plans to sponsor future efforts on the reevaluation of the CHESS data. Such studies will include data on asthma in New York City during 1971–72, chronic bronchitis in New York City, cardiopulmonary disease in New York City, and pulmonary function in schoolchildren in Birmingham, Alabama, and Charlotte, North Carolina.

Coal Gasification Technology Moves Ahead

"The recently announced participation of the federal government in a coal gasification test facility should speed the day when this new technology can be used to generate electricity," said EPRI's Dwain Spencer, commenting on last week's announcement by ERDA to commit $1.8 million to Commonwealth Edison Co. for the further design of a coal gasification–combined-cycle gas turbine test facility. When built and operated at Commonwealth Edison's Powerton site near Pekin, Illinois, the facility will produce 25 MW of electricity.

Most of the nation's electric utilities, which represent about 80% of U.S. generating capacity, have supported the initial design efforts of the Powerton test plant since March 1974 through their membership in EPRI. Commonwealth Edison has supported this effort with its own funds, as well as through its contributions to EPRI's research program.

Tests conducted at Powerton should lead to a demonstration of this new type of coal-fired power plant by 1985.

"The coal gasification–combined-cycle power plants promise higher efficiencies and less environmental impact than conventional coal-fired power plants," said Spencer, director of the EPRI Advanced Fossil Power Systems Department. According to Spencer, these systems offer the greatest potential for increasing our country's use of coal in a way that is environmentally acceptable and in accord with the goals of the president's recent energy message.

Powerton's gasification unit will be based on the technology developed by Lurgi Mineraloltechnik GMBH of West Germany. The Powerton system will produce a gas (with a heat content about one-seventh that of ordinary natural gas) by reacting coal under pressure with a mixture of air and steam. The gas will then pass through a cleanup system and desulfurizer before being fired in the gas turbine.

"By removing such emission-forming constituents as particulates, nitrogen, and sulfur compounds from the gas prior to combustion, power systems based on coal gasification offer significantly reduced emissions compared with today's coal-fired units," according to EPRI's Neville Holt.

One of the main reasons for the high efficiency of the gasification process results from its integration with the combined cycle. In a combined cycle, waste heat from the gas turbine is used to make steam for a separate turbine-generator instead of being dissipated into the environment as occurs with most gas turbines.

"These plants should be able to provide more kilowatts of electricity per ton of coal than conventional power plants," stated Holt, manager of the EPRI Clean Gaseous Fuels Program. "In addition, these advanced power plants will require much less land and only 60–70% of the water needed by present coal-fired plants."

Under the proposed budget for the Powerton plant, ERDA will provide $115.6 million of the total funding. EPRI will contribute $30 million; Commonwealth Edison, $14.2 million; and the State of Illinois, $7.2 million.

Study Finds Continued Fuel Price Increase

The price of fuels will continue to increase up to the year 2000, according to a report by Foster Associates, Inc., of Washington, D.C., which was released in April by EPRI. The study developed price projections on a regional basis, both at points of production and at points of consumption.

Although future energy prices involve many uncertainties, the report asserts that even without inflation, the price of all forms of fuel will increase substantially.

The report, *EA-411, Fuel and Energy Price Forecast*, Vol. 1, *Final Report*, and Vol. 2, *Schedules*, notes that the price of uranium, the fuel for nuclear power reactors, is especially uncertain. "Uranium is one energy source that has many unanswered questions in respect to requirements, the size and nature of the resource base, and the costs of exploration and production," the report states.

According to Thomas Browne, an EPRI project manager, the study was made to provide input to the forecasting efforts of the EPRI Energy Supply Program. Browne noted that as with all contractor reports the publication of this report does not imply EPRI's endorsement of the analysis or conclusions.

An important conclusion of the report is that the Organization of Petroleum Exporting Countries (OPEC) will continue to be a dominant force in determining the price of world oil up to the year 2000. In addition, world oil prices will continue to influence other energy prices in the U.S., although this inflation will lessen considerably in the 1990s because of the rising cost of domestic energy sources.

For the year 2000, the report forecasts that the average cost of domestic and imported crude oil in 1975 dollars, will be about $18 per barrel, ranging from about $10 to $24, which reflects the uncertainty of the forecast.

For gas from all sources at points of

production, the most likely case shows the average price to be just over $3/million Btu in 1975 dollars. The range for the gas price forecast is from $1.50 to $4/million Btu.

Bituminous coal costs at the mine, in 1975 dollars, will vary depending on type of mine and region. For eastern high-sulfur coal, the low price will be around $23/ton, with a high price of $26/ton. Midwestern high-sulfur coal will be about $21/ton. Western low-sulfur coal will have a low price of $25/ton and a high price of $31/ton.

The most likely cost of uranium in the year 2000 is projected as $74/lb, with a range of $44/lb to $134/lb, reflecting the uncertainty in the projection.

The price of uranium must be interpreted somewhat differently than other fuel prices because of the long time required to build a nuclear power plant and secure the necessary licenses. The prices quoted above reflect uranium purchased in the year 2000 for delivery approximately 10 years later. Uranium burned in nuclear reactors in the year 2000, for example, would be produced from uranium purchased in 1990.

EPRI Joins Air Pollution Health Effects Study

EPRI announced in April that it had joined the federal government in sponsoring "what is probably the most important ongoing environmental health study in the U.S. today," according to the manager of EPRI's Health Effects Program.

James McCarroll, M.D., stated that a $378,000 EPRI award to the Harvard School of Public Health will support a role for the electric utility industry in a project funded by the National Institute of Environmental Health Sciences (NIEHS).

"This project is the largest epidemiological study of the health effects of air pollutants on humans in the U.S. today. It is well conceived, comprehensive, and significant in terms of both sample size and funding," said McCarroll.

The study focuses on six communities in the U.S. and involves samples of 1600 to 2400 adults in each community. Children are also being studied. The project has been under way since 1974, with approximately $3.5 million total cost committed through 1979 from NIEHS. If further federal funding is approved at that time, the study is expected to last through 1983.

The six communities under investigation are: Watertown, Massachusetts; Kingston-Harriman, Tennessee; the southern end of St. Louis, Missouri; Steubenville, Ohio; Topeka, Kansas; and Portage, Wisconsin. The plan calls for investigators from the Harvard School of Public Health, under the direction of Benjamin Ferris, M.D., to collect, correlate, and analyze health and air quality data in these communities. Socioeconomic and meteorologic conditions in the areas are also being studied.

Investigators are collecting health assessment data on adults and children by conducting personal interviews and administering lung function tests. Adults are retested every three years; children are retested annually.

"The real payoff in the study should come with the children because any effects of air pollution may be more discernible in developing lungs," stated McCarroll.

Air quality in the communities is being measured with three types of monitoring devices. One type measures concentrations of air pollutants at a fixed location in each community. This central location serves as a reference point for a network of samplers positioned throughout the community.

A second instrument measures air pollutant levels inside the homes of at least 10 volunteers from each community for a year. Samples are taken in the room where the family spends most of its time.

The third measure of air quality is provided by a portable monitoring device that volunteers from the sample carry with them every six days. The monitoring device collects a 24-hr integrated sample of all the pollutants to which the volunteer is exposed in traveling throughout the community.

"Most other studies have only measured air pollution levels at fixed locations in a community," McCarroll pointed out. "This is the first time that a major study has also monitored pollution levels within the home and on a communitywide exposure basis. By taking into account all three measures, we hope to get a more comprehensive picture of the effects of air pollutants on human health."

EPRI Negotiates 30 Contracts

Number	Title	Duration	Funding ($000)	Contractor / EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP367-2	Phase Equilibrium in Coal Liquefaction Processes	2 years	349.3	Purdue Research Foundation *L. Atherton*
RP779-13	Experimental Fabrication and Evaluation of Materials for Letdown Valves	4 months	34.2	Battelle Columbus Laboratories *H. Lebowitz*
RP786-3	By-product Waste Disposal for Flue Gas Cleaning Processes	9 months	117.3	Envirotech Corp *T. Morasky*
RP911-1	Metal Temperatures and Thermal Stress in Cyclic Turbines and Boilers	43 months	702.9	Westinghouse Electric Corp. *D. Ansen*
RP922-2	Definition and Conceptual Design of a Small Fusion Reactor	2 years	250.0	General Atomic Co *F. R. Scott*
RP928-3	Hydrocarbon Expander Turbine Design	5 months	50.9	Rotoflow Corp *G. Underhill*
RP980-3	Coal Preparation Using Magnetic Separation	5 months	50.0	Sala Magnetics, Inc. *S. Venkatesan*
Nuclear Power Division				
RP130-3	Nuclear Reactor Core Benchmark Data	12 months	171.9	General Electric Co *R. Whitesel*
RP350-10	Analytic Fuel Rod Modeling in Support of the Studsvik Inter-Ramp Test Project	6 months	9.7	Science Applications, Inc. *A. Roberts*
RP822-2	A Program to Develop a Portable Radiographic System for In-Service and Repair Instruction	3 months	292.2	Southwest Research *E. Reinhart*
RP825-1	Radiation Control in the Primary Coolant Loop of PWR Plants	42 months	467.3	Babcock & Wilcox Co *R. Shaw*
RP889-3	Development of a System Transient's Simulator	22 months	350.0	Energy Incorporated *L. Agee*
RP894-1	Limiting Factor Analysis of High-Availability Nuclear Plants	15 months	347.7	General Electric Co *R. Swanson*
RP966-1	Properties of Colloidal Corrosion Products and Their Effects on Nuclear Power Plants	2 years	291.4	Clarkson College of Technology *T. Passell R. Shaw*
RP967-1	Chemistry of Corrosion-Producing Salts in LWR Systems	1 year	88.6	Babcock & Wilcox Co *T. Passell*
RP975-1	Nuclear Data File Development and Standardization Activities	9 months	100.0	Brookhaven National Laboratory *O. Ozer*
RP975-3	Nuclear Data File Development and Standardization Activities	1 year	80.0	Union Carbide Corp *O. Ozer*
RP975-4	Nuclear Data File Development and Standardization Activities	6 months	40.0	Rensselaer Polytechnic Institute *O. Ozer*
RP978-1	Evaluation of the Potential of Spectrum-Shift Control Concept With Uranium Fuel	6 months	131.8	Combustion Engineering, Inc. *C. Lin*
RP1019-1	Alternative Void Fraction System Development	15 months	123.8	Auburn International, Inc. *D. Cain*
RP1020-1	BWR Turbine Trip and Plant Stability Testing	13 months	132.9	General Electric Co *R. Whitesel*
Electrical Systems Division				
RP847-1	Gases Superior to SF_6 for Insulation and Interruption	31 months	750.0	Westinghouse Electric Corp *E. Norton*
RP985-1	Transformer Noise Abatement, Phase II	23 months	248.5	Allis-Chalmers Corp *E. Norton*
RP7860-1	Water Jet Concrete-Cutting System	12 months	277.2	Flow Research, Inc. *T. Rodenbaugh*
Energy Analysis and Environment Division				
RP881-1	Effects of Thermal Power Plants on Aquatic Environmental Program	1 year	100.0	National Economic Research Associates, Inc. *R. Wyzga*
RP1001-1	Health Effects of Sulfur Oxides and Particulates	3 years	378.1	Harvard University, Office of Research Contracts *J. McCarroll*
RP1002-1	Prevention of Golden Eagle Electrocution by Power Poles	3 years	34.3	Brigham Young University *R. Goldstein*
RP1007-2	Regional Electricity Consumption Forecasting	4 months	38.2	Wharton EFA, Inc. *R. Crow*
RP1013-1	Supply Problems in the Development of the Solar Heating and Cooling Industry	17½ months	110.0	Donovan, Hamester & Rattien, Inc. *R. Urbanek*
RP1018-1	Geostatistical Estimation of Uranium Supply	14 months	74.9	Harvard University *J. Platt*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

The mechanical design of overhead transmission lines must accommodate the effects of wind loading. Wind is a dynamic, nonuniform force that can cause two problems: conductor oscillations and transverse loading stresses on sections of transmission line. The overhead transmission mechanical research subprogram is studying both problems.

Conductor motion studies and damper development are concerned with wake-induced oscillations. Designing for transverse wind loads is undertaken in separate projects.

A project on wind-induced conductor motion is now under way (RP792). It concerns the three forms of conductor motion: aeolian vibration, galloping, and subconductor oscillation. The investigators soon discovered that although this subject had been extensively researched throughout the world, very little of the information could be correlated and very little was available in one place. One outcome of the project will be the publication of the fourth EPRI transmission line reference book. This will present both published and previously unpublished data in a form usable by the line designer. The reference book will contain theoretical causes and practical solutions for dealing with conductor motion and will include a section on fatigue.

The project was started in late 1976 and is expected to be completed by early 1978. The contractors are Alcoa Conductor Products Co. on galloping, fatigue, and subconductor oscillation, Boeing Engineering & Construction on subconductor oscillation, and Washington State University on aeolian vibration. Commonwealth Associates Inc. will coordinate and edit the final published document.

One type of conductor motion, galloping, has long been of concern to transmission line engineers. Recent increased emphasis on more attractive and compact overhead line designs intensifies the industry's interest in resolving the problem, despite years of unsuccessful attempts. EEI, IEEE, and CIGRE have for some years promoted efforts toward the solution of this wind-induced problem.

Ontario Hydro has been very active in research to conquer galloping and has tested many possible solutions on test spans and operating lines within its system. Most attempts to control motion have used damping devices installed on the conductors or towers. Ontario Hydro has recently developed a device called a galloping detuner that has shown promise of resolving the majority of galloping problems. The device is reasonable in cost and may be attached to new or existing lines, much as a vibration damper or spacer is now installed. It separates the torsional and vertical natural frequencies of the span. The theory is to inhibit initiation of motion rather than to absorb the energy of an already moving conductor, as with a damper.

To obtain in-service experience on the device, Ontario Hydro has developed an expanded field evaluation program with EPRI (RP1095). Installation of galloping detuners on existing spans of about six U.S. utilities is planned for late 1977. Through evaluation of the projected test spans in the U.S. as well as in Canada, it is hoped that this long-standing transmission line problem can soon be controlled.

An unexpected benefit from a recent project on compact transmission line design with Power Technologies, Inc. (PTI) has been an increased understanding of transverse conductor wind loading (RP260). This is the least well defined contributor to tower loading. Substantial savings in structure cost, as well as a reduction in the necessary clearance requirements in high-wind areas, can be obtained by developing the concepts identified.

PTI's test line data correspond to earlier data from the Hornisgrinde test site in Germany. However, they indicate loadings substantially less than those obtained by using the time-honored equation for calculation of wind pressure on a conductor.

Figure 1 shows the trend of loading versus wind speed given by the two methods. The essential difference is that the PTI work and the German work take advantage of the fact that for most span lengths the wind speed is not the same at all points along the span due to gusting. This fact, although recognized, has not been investigated to any significant degree in the U.S. Although preliminary work performed in the U.S. and in Europe confirms the benefits that can be derived, it does not provide sufficient data for application of the clearance reduction factors in the various situations required. It has shown that the amount of reduction increases with higher wind speed as well as with span length.

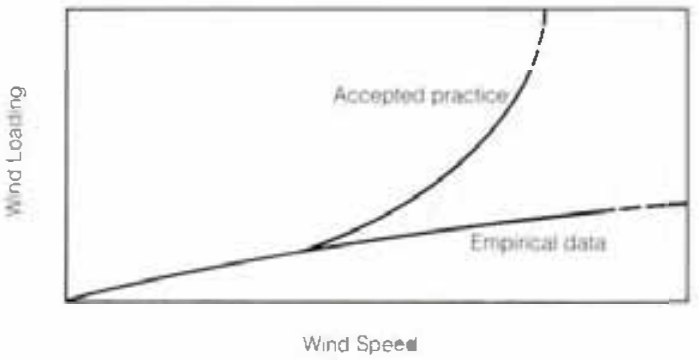
To solve this problem and to make savings in tower steel and clearances, an evaluation program is being developed. It will be necessary to determine (1) how uneven wind gusts—which are distributed in time and space on the line—affect loading, (2) how different types of terrain cause wind-gust variations, and (3) how the gustiness varies at different average wind speeds.

An EPRI workshop was held to discuss ways of investigating reductions in wind loading without sacrificing reliability. A project may soon be under way that will make possible significant savings to line designers, particularly in areas of severe wind conditions. *Project Manager: Mike Silva*

Environmental effects of dc lines are rapidly assuming increased importance to the U.S. utility industry. Electric field effects have been one of the primary reasons used by utility intervenors to block construction of ac high-voltage transmission lines. Regulators are now beginning to apply ac field criteria to dc lines, even though the field conditions are widely different. This places a severe cost penalty on the dc line.

Very few data have been published on dc

Figure 1 Comparison of calculated and measured transverse wind-loading pressures on transmission lines. Wind gusts, which are uneven and distributed along the line, appear to account for the difference between the curves at higher wind speeds. When properly documented, wind data may make possible some modifications in loading criteria and a resulting reduction in steel requirements.



fields because of the lack of suitable instrumentation. Accurate prediction and measurement of electrostatic fields is absolutely necessary to establish a verifiable facts base that is responsive to public inquiry. The few instruments available have been uniquely developed by each investigator and have only modest correlation between each other. If commercial dc field instrumentation were available to all interested parties, the mystery surrounding dc field effects could soon be removed and reasonable dc line design criteria could be set, unbiased by ac line problems.

The line parameters of interest in quantifying the severity of any environmental impact are electrical field strength, ion density, and current density. An EPRI-sponsored project with Westinghouse Electric Corp. as the main contractor and System Planning Corp. as a subcontractor will develop an instrumentation package that can be produced on a commercial basis (RP1046). The instruments are designed to take measurements not only at ground level but also in the air. They should be suitable for long-term recordings and direct readouts and should provide connection to recorders or telemetry for unattended operation. An operator's remote-display and readout unit may eliminate effects on the calibration and performance of the instrument caused by the operator's presence (Figure 2).

The instruments will probably be unattended for long periods while measuring ion drift or the effect of weather parameters on dc line fields. For this reason the feasibility of automatically controlling sensitive instruments will have to be investigated.

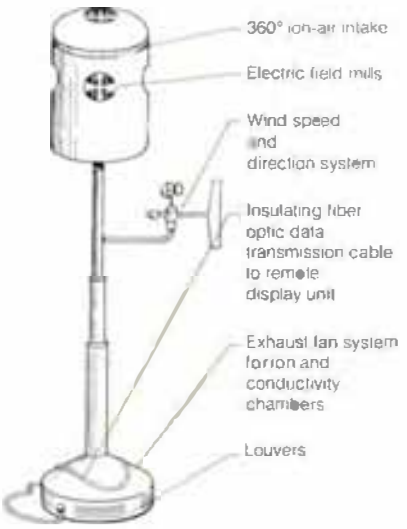


Figure 2 Proposed design approach for integrated dc field strength instrumentation (RP1046). The head contains two conductivity chambers, two ion-charge counters, four electric field mills, and a zero-charge system.

Successful completion of the project should provide the industry with new tools for obtaining a better understanding of dc transmission line performance, thus providing utility engineers and the public with added confidence in these circuits as important links in the nation's power systems. *Project Manager: Lennart Svensson*

Substations

The growth of power transmission systems steadily increases the short-circuit-interrupting requirements for power circuit breakers. There are systems today in which the breaker-interrupting requirements are at or near the rating of the largest breakers available; today's breakers will quickly become obsolete. With growth in system capacity, greater load-current-carrying ability is also needed.

SF_6 gas is considered the best medium in which to provide high-current and high-voltage interrupting performance. Heavy-duty, transmission-class, SF_6 power circuit breakers have used double-pressure systems to provide gas flow during arc interruption. These systems require that breakers be equipped with insulated, high-pressure gas reservoirs and compressor systems (with their control devices), both of which are costly and require additional maintenance.

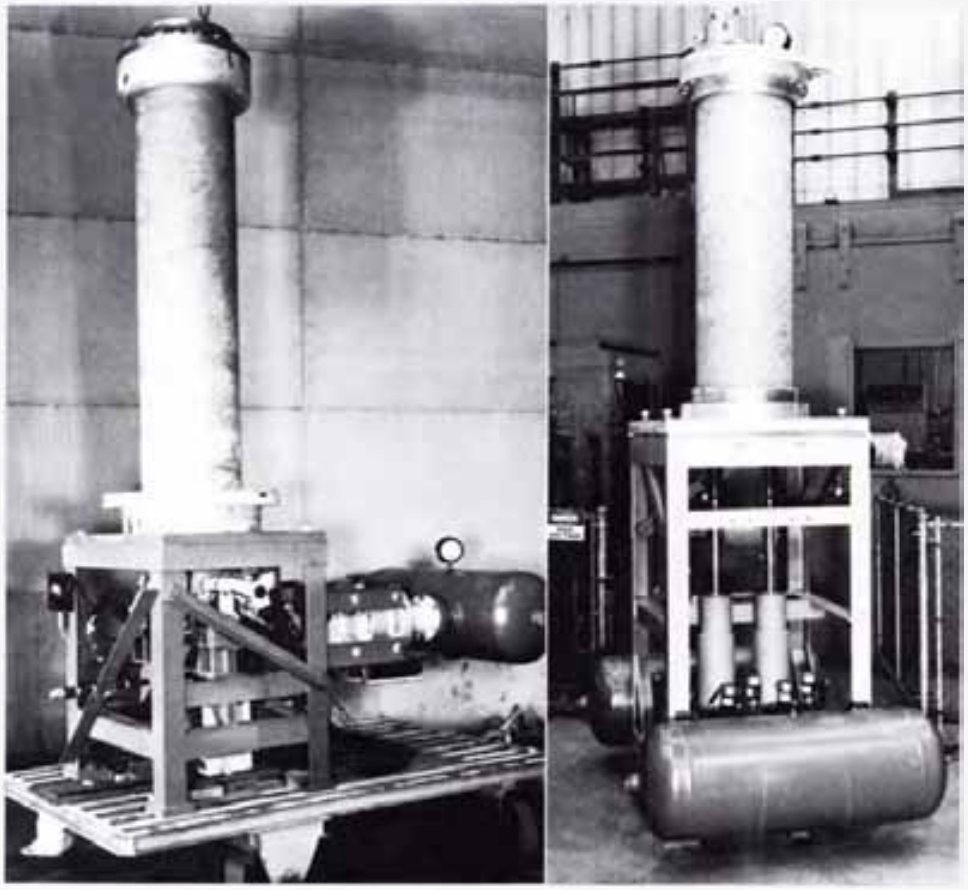
Recognizing these problems, EPRI has funded a project with Westinghouse Electric Corp. to develop a single-pressure, SF_6 interrupter rated to interrupt 120 kA at 145 kV in two cycles or less (RP478). It would have a continuous-current rating of up to 4000 A (Figure 3).

One of the problems is to maintain a safe temperature rise of current-carrying components without an excessive increase in material and mass of moving parts. This is necessary to keep the breaker-operating energy at a reasonable level.

A test is being conducted to determine interrupter materials performance in the high-temperature, high-pressure, SF_6 environment (which is contaminated with arc products). The goal of this portion of the project is to evaluate insulating materials that will give reliable performance at 135°C and conductor materials, at 150°C.

Today's single-pressure puffer breakers are of moderate interrupting rating and use moderate gas pressures (75 psi). It is known that the interrupting ability of SF_6 improves as its pressure around the arc is increased. Accordingly, two approaches to a higher-pressure SF_6 interrupter design are being investigated on this project. One is a super-pressure (300 psi), SF_6 gas puffer interrupter;

Figure 3 Laboratory models of a superpressure circuit breaker interrupter (left) and a liquid SF_6 circuit breaker interrupter, built and tested to provide data for design of a prototype interrupter (RP478). Both models successfully interrupted 90 kA at 145 kV early in 1977. One will be selected for final development of an interrupter with a continuous-current rating of 4000 A.



the other is a liquid SF_6 interrupter. Both use piston action during opening to provide flow of SF_6.

Full-scale model interrupters of each type have been built and successfully tested at 90 kA, providing the needed high-current interruption performance data. These data, together with those on hand for lower-rated breakers, will provide the necessary information for the design of both types of high-duty interrupters. The two designs will then be evaluated by EPRI. One will be selected for ultimate development of a prototype interrupter. The project is scheduled for completion in late 1978. *Project Manager: Glenn Bates*

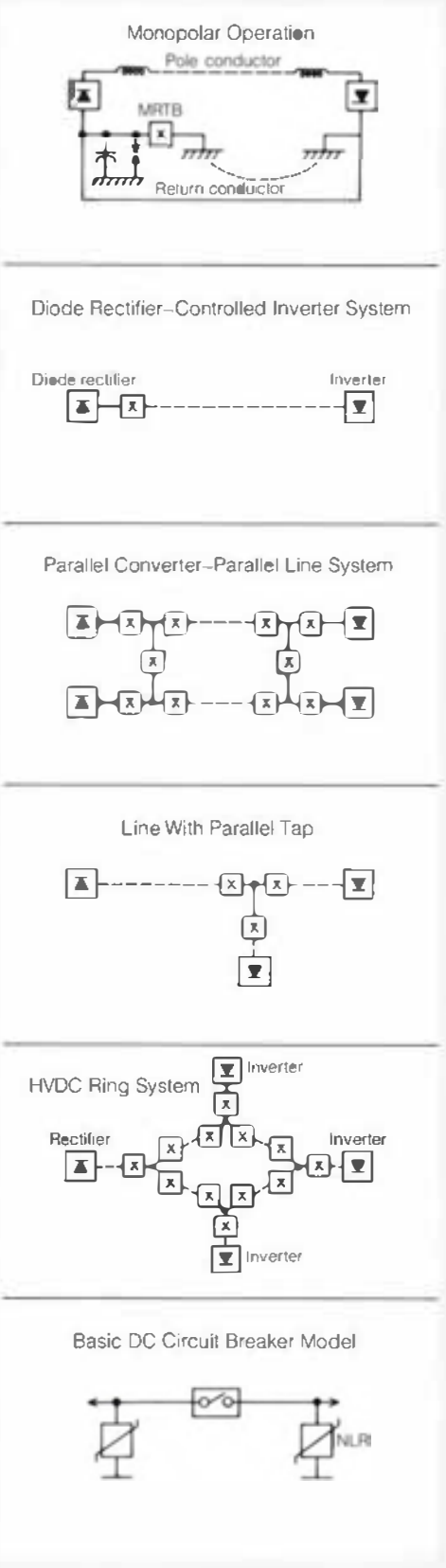
Dc circuit breakers

Dc circuit breakers are the subject of renewed interest in view of expanded use of HVDC systems. The concept of multiterminal dc systems using parallel-connected converters was discussed in the literature more than 15 years ago (*1*). In the U.S., several HVDC projects under consideration could develop into multiterminal, interconnected HVDC systems. However, lack of dc circuit breakers is most often cited as the reason for not considering multiterminal dc schemes seriously.

Ideally, the breakers should operate independently, that is, without depending on converter control system operation. However, some interaction between the breakers and the converters is unavoidable. It will doubtless take a number of system studies to support a careful development of dc breakers before utilities will commit resources to implement a multiterminal dc system. Recognizing this, EPRI is conducting a study being performed by Hydro-Quebec Institute of Research that will provide basic information about the duties of different dc circuit breakers and the interactions between the breakers and the dc system in four basic multiterminal dc schemes (RP326).

The different concepts are shown in Figure 4. The study also covers diode rectifier con-

Figure 4 System concepts for application of dc circuit breakers (RP326).



cepts and the application of metallic return-transfer breakers (2). It concentrates on parallel operation of converter terminals but excludes series-connected converter terminal schemes because parallel connection of converters is probably the most realistic approach for systems where independent load control is needed for each converter terminal.

The first phase of the project consisted of a set of preliminary system studies for the different concepts. These studies have been used to define the system parameters of importance and to evaluate and develop the control sequences needed for each circuit breaker application. The preliminary studies used the basic dc circuit breaker model (Figure 4). Other breaker concepts have been developed that are based on information supplied from manufacturers.

The last phase of the project is a set of final system studies that use system concepts proposed by or of interest to U.S. utilities. The study will result in a dc breaker specification outline. It will discuss the breaker requirements for fault clearing, reclosing, load break, and closing on load. It will take into account the interaction between the control system and the breaker. Further, overvoltages generated by the dc circuit breaker, the energy dissipation, and the breaker's speed of operation will be considered.

As expected, a preliminary study showed that the breaker specification is highly sensitive to the control system performance. It has not been possible to optimize the dynamic response of the control system for each application. However, realistic delays in the control sequences equal to expected delays in communication lines have been inserted into the simulator model. Even though significant differences exist between control systems built by different dc suppliers, the study is intended to be generic and of value to the whole industry. Some of the early results have been published (3). The final project report is expected to be available later this year. *Project Manager: Stig Nilsson*

UNDERGROUND TRANSMISSION

A project with Ohio State University (OSU) will be to develop an accurate and expedient method of detecting, identifying, and mapping underground obstacles (RP7856). The hardware developed should prove to be an important new tool that utilities can use to plot an optimal cable route before trenching.

OSU's system for sensing obstacles employs a high-frequency, electromagnetic pulse of approximately 150-μs pulse width at 1000-V peak amplitude. The pulse is sent into the ground via a transmitting, folded dipole antenna (Figure 5). This is a pulsed radar type of system with a frequency spectrum of 250 Hz–1 GHz. A receiving antenna positioned at 90° to the transmitting antenna picks up the scattered reflections from the obstacles in much the same way that sonar detects naval vessels. By knowing the velocity of propagation, soil dielectric constant, and soil conductivity (electrical), the depth of an obstacle can be calculated. The size of the obstacle is determined from the reflected signal's amplitude. By referring to a data base of reflection signature profiles, a comparative analysis can be performed to characterize the obstacle by size, shape, depth, and material. It is anticipated that this location device may be able to detect objects 20–40 ft underground. It should be able to focus on a 3-in target at a 4-ft depth and have a resolution between obstacles of less than 1 ft. *Project Managers: Tom Rodenbaugh, William Blair*

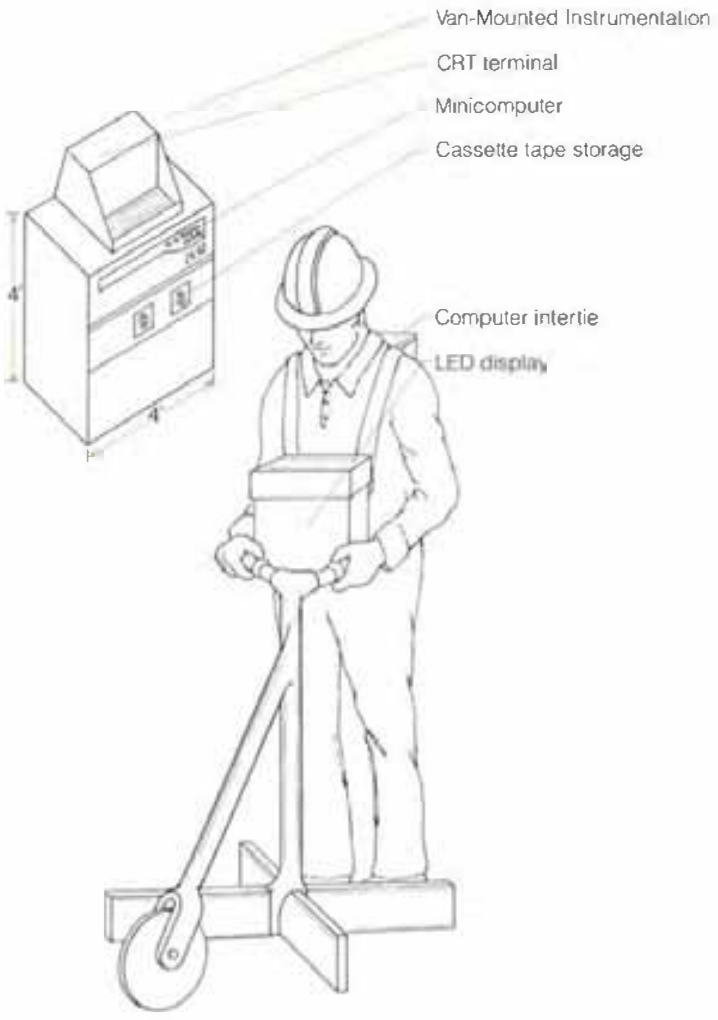


Figure 5 Folded dipole antenna similar to that being developed under RP7856 for locating underground obstacles. Ohio State University will design and build expanded instrumentation, including a minicomputer, mapping unit, and sampling oscilloscope.

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1. U. Lamm, E. Uhlmann, and P. Danfors. "Some Aspects of Tapping of HVDC Transmission Systems." *Direct Current*, May 1963.

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R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

RESEARCH STRATEGY ON HEALTH EFFECTS

A major aim of the Environmental Assessment Department's research program is to provide reliable data on any possible health effects linked to electricity generation and use so that rational policy decisions can be made and cost-effective control technology put to use as needed. This is a complex and ambitious task. To accomplish it with any measure of success requires a chain of disciplinary studies to:

- Determine what significant pollutants are emitted and in what physicochemical form
- Establish reliable methods for their measurement and monitoring
- Determine transfer routes, movement rates, and conversion during transport from the source to the population exposed
- Estimate relative contributions of major sources to population exposures
- Analyze critically existing biomedical data
- Screen potentially significant pollutants, determine mechanisms of toxicity, and establish dose-response relationships in animal toxicology studies
- Apply the results of animal toxicology studies to selective clinical trials in human beings
- Use epidemiological studies in combination with other biomedical data to provide human risk assessment (i.e., to quantitatively predict effects of environmental agents of concern on human health)

When EPRI's program started over two years ago, it was decided that major emphasis would be placed on air pollution from fossil fuel combustion. The main reasons for this were that a rapidly increased use of coal was anticipated; there was relatively little known about population effects from coal combustion; air pollution was the major route of population exposure to pollutants from the burning of coal; and the most effective way for air pollutants to exert their harmful effects is through inhalation.

The first four steps noted above are primarily physical in nature and were begun first. Currently EPRI has about 25 projects in this area with authorized funding for about $9.5 million over the next two to three years. A large part of this funding is for the sulfate regional experiment (SURE), about $5.5 million. In addition to investigation of sulfur compounds, there are also studies of nitrogen oxides, polycyclic organic materials, oxidants, and trace elements. This phase of the work is well under way.

Analysis of existing biomedical data is being done primarily by Greenfield, Attaway & Tyler, Inc., under RP681, which started in September 1975. Two groups of reports are to be prepared. One deals with specific substances and covers sulfur oxides (sulfur oxides: current status of knowledge, EPRI EA-316), nitrogen oxides, particulates, and oxidants. The other group consists of detailed reanalysis and interpretation of EPA epidemiological data. The first report has been completed (*Evaluation of CHESS: New York Asthma Data 1970–71*, EPRI EA-450). Others in this series will include New York City asthma data for 1971–1972, chronic bronchitis in New York City, cardiopulmonary disease in New York City, and pulmonary function in schoolchildren in Birmingham, Alabama, and Charlotte, North Carolina. Using research results from this project, the contractors have been able to testify effectively on behalf of several utilities at legislative hearings.

The animal toxicology studies have just recently been established and are expected to begin soon. A three-year coordinated program funded at about $3.5 million is planned for these studies (RP1112). The work will be done by three research teams at the Massachusetts Institute of Technology and the University of California at Davis and at Irvine. At MIT, aerosols will be produced and characterized under controlled conditions, simulating actual combustion products. Their relative irritant potency will then be assessed. At U.C. Irvine, further studies on the effects of these compounds and others will be carried out with rodents and dogs, using mixed atmospheres containing sulfur oxides, nitrogen oxides, and ozone in combination with metals in aged atmospheres. Young animals will be included in the experiments so that physiologic tests can be developed for follow-up human studies. At U.C. Davis, an interdisciplinary team from the Primate Center and the Veterinary, Medical, and Engineering schools will carry out studies on long-term exposures (three to nine months) to various pollutants.

Full-scale research programs for clinical trials on human beings and epidemiology are still in the planning stage and will probably be implemented in 1978. These are to be large-scale projects and will likely be done in cooperation with federal agencies. In the meantime, EPRI has joined with the National Institute of Environmental Health Sciences in an epidemiological investigation conducted by Harvard University, School of Public Health, to determine the health effects of air pollutants on children and adults in six U.S. communities (RP1001). The Health Effects Program is being managed by James McCarroll, M.D. *Director, Environmental Assessment Department: Cyril L. Comar*

TOOLS FOR TECHNOLOGY ASSESSMENT

Assessing the probable impacts of new energy technologies and policies is often realistic only when they are considered within the context of the total energy system from the primary resources to points of end use. Electricity offers a good example. Much of the concern for and analysis of electricity centers on the pollution, safety, and inefficiency characteristics of power generation, while the counterbalancing effects at the point of end use are neglected. Electricity is the cleanest, safest, and most efficient of all commonly used energy forms. Electricity at end use can be considered a fuel, competing with the direct combustion of coal, oil, and gas. In many applications involving such technologies as heat pumps, electric automobiles, and steelmaking, the environmental and end-use efficiency benefits from electricity may more than offset the emission effects and inefficiencies incurred in the generating process.

An energy systems analysis study that takes into account all the trade-off effects between production and use shows the overall impacts of electrification in the most realistic manner. Similarly, the assessment of numerous other energy technologies and policies can benefit from such a comprehensive overview. The recently published *Regional Reference Energy Systems (RES)* (EPRI EA-462), developed for EPRI by Brookhaven National Laboratory (BNL), and a Computation Procedure for Applying Reference Energy Systems (COMPARES), provide the methods, data, and computation tools for conducting these assessments of energy technologies and policies.

RES are sets of structured data and projections that represent the flow of a nation's or region's energy through a network of technical activities from its primary energy resources to its ultimate end use. These activities include the processes of extraction, refining, transportation, central conversion, distribution, and use. Each activity (e.g., coal-steam electric power generation) is quantified by the amount of energy that flows through it and by coefficients that specify its energy efficiency, environmental effects, and costs. RES are developed for a historical base year and for key future years based on projections from various sources, such as the U.S. Census Bureau, FEA, and ERDA.

BNL initiated the work on RES in 1971 for the U.S. Office of Science and Technology, specifically for the assessment of energy technologies by that office and other government agencies. The purpose was to provide a reasonable and consistent framework for gauging the range of effects from the application of alternative technologies. Since its development, the RES concept has been used extensively by ERDA as an R&D planning tool.

Regional RES

Since the effects of energy technologies will be influenced by a wide range of regional variations, RES were regionalized to allow for these variations. This provides a level of precision more in line with EPRI's analytic requirements for technology assessment. Under EPRI's contract with BNL, RES have been developed for each of nine census regions, for the U.S. as a whole (a summary of the regional data), the New York Power Pool, and the TVA service regions (RP442). RES were formulated for the 1972 base year and projections developed for 1980, 1985, and 2000. The RES are base case scenarios representing "most likely" patterns of energy consumption under somewhat status quo conditions. They were formulated with a minimal introduction of new technologies and with allowances made only for moderate conservation measures. RES are not forecasts of what the energy future will be. Their intent is to provide a reasonable energy condition from which to gauge the effects of change brought about by the possible introduction of new technologies, strong conservation initiatives, or alternative energy policies.

Application of RES

The RES are in balance, that is, the energy from the primary resources, when multiplied by the various efficiencies through all of the technical activities, equals the amounts required at the end use. Multiplying the quantities of energy flowing through the technical activities by the respective environmental and cost coefficients, and summarizing these calculations, determines the inventory of environmental effects and the total system's energy cost.

The application of RES for technology assessment and energy policy analysis is accomplished through COMPARES, an accounting procedure and computer program developed at EPRI for this purpose. The COMPARES procedure is quite straightforward. First, the resource requirements, environmental emission effects, other environmental effects, and total energy system costs are calculated for a given RES. Next, a revision is introduced to RES. The revision is formulated to represent, for example, the introduction or improvement of technology, an energy conservation measure, or a restriction in supply. The formulation of a revision to simulate such events may involve only the simple replacement of a process efficiency or may require several alterations to RES parameters. The revised RES is rebalanced through adjustment in the supply of primary resources to meet final demand requirements, and the environmental effects and costs are recalculated. Finally, the difference in effects between the original RES and its revised version determines the net effect of the revision, thereby representing the impacts of the technology or policy option or event being analyzed.

COMPARES allows this procedure to be carried out easily, quickly, and inexpensively, making it practical to assess a large number of technology or policy cases in a short time. Each COMPARES output is the net impact for each technology or policy case in terms of the requirements for specific energy resources, first-order environmental effects, and total energy costs. These determinations can be calculated directly for the key reference years 1980, 1985, and 2000. By interpolation they can also be assessed for any year between 1972 and 2000, and by extrapolation for years out to 2010. Cost effects for years in this interval can be discounted back to any base year at any specified discount rate.

The most important aspect of this analysis is that all the trade-off effects between energy production and use are accounted for, offering an important overview assessment of technological change. *Project Manager: Ron Michelson*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

MATERIALS FOR COMBUSTION ENVIRONMENTS

Most alloys used for high-temperature combustion service operate in oxidizing environments, where they are protected by oxide scales such as Cr_2O_3 or Al_2O_3. In pulverized-coal-fired boilers, oxidizing conditions are maintained so as to minimize corrosive attack by sulfur- or carbon-bearing constituents in the combustion gases.

Coal gasifiers and fluidized-bed boilers, however, involve low-oxygen environments and thereby pose special challenges in the selection of structural materials. Oxidation, nitridation, sulfidation, and carburization—all can occur. Other equipment and processes are at least potentially involved: gas turbines, and coal gas- and liquid-fired boilers. Several EPRI projects address these related circumstances, seeking better bases for selecting or designing materials to resist corrosion and erosion.

Breakdown of protective oxides

Lockheed Missiles & Space Co., Inc., Palo Alto Research Laboratory, with a subcontract to Ohio State University, has the responsibility to sort out the complex chemical reactions involved in corrosion in gasification and fluidized-bed combustion (FBC) conditions (RP716). For a forthcoming interim report, the ranges of stability of various possible phases in the alloy systems A-O-N, A-O-S, A-O-C, A-S-N, A-S-C, A-C-N have been calculated (where A is one of the three important base materials, iron, nickel, or cobalt; or one of the important alloying elements, chromium, aluminum, or manganese; and O, N, S, and C are the oxidants). This report will be valuable in interpreting the corrosion products formed on alloys. The Ohio State subcontract is concerned with the transition from nonprotective internal oxidation to protective external scales in low-oxygen activity environments.

The program is also examining corrosion in superheater and reheater tubes of conventional pulverized-coal-fired boilers. Foster Wheeler Energy Corp. and the International Nickel Co. have joined forces (RP644) to reexamine this old problem from a modern alloy design point of view. As in all EPRI material design projects, the initial phase is to evaluate the mechanisms whereby state-of-the-art materials fail in a simulated test. Compositions and microstructures then are designed to overcome the mode of failure. Coupon specimens coated with a simulated coal ash are exposed for 250–500 hours to 675–790°C (1250–1450°F) flue gas containing SO_3, which produces alkali iron trisulfate, the agent believed responsible for fireside corrosion. A wide variety of standard, advanced, and experimental alloys are being studied. Preliminary analysis of the results indicates that chromium, aluminum, niobium, and silicon alloying additions reduce corrosion. Ferritic alloys may be more effective than austenitic in that only half as much chromium is needed for equivalent improvement in fireside corrosion resistance. Molybdenum appears to be detrimental, and manganese is moderately ineffective.

Foster Wheeler is also examining the effects of alloy chemistry and surface treatments on exfoliation from boiler tube alloys. Steam-side exfoliation during cooling or heating involves magnetite-type scale greater than about 6 mils thick. The spalled scale can cause tube plugging and ultimate failure from overheating, or it can be swept into the turbine and cause erosion. Foster Wheeler has identified the preoxidation of ferritic boiler tubes in pressurized water to be a treatment of particular interest. It might be adapted, in situ, to operating boilers.

Extensive experience with the exfoliation problem has also been obtained by Great Britain's Central Electricity Generating Board and is being summarized in a technical planning study on the spalling of steam-grown oxides from superheater and reheater tubes, which will be available in late 1977 (TPS76-655).

Although gasifier reactor chambers are generally refractory-lined, metallic parts are needed in transfer lines, valves, and cyclones. In addition to corrosion by reactants like sulfur and carbon in the low-oxygen-activity environment, these components are subject to erosion from solids like coal and ash in the gas stream. Battelle, Columbus Laboratories and the Cabot Corp. Stellite Division, are studying the design of corrosion-resisting metallic materials for coal gasification and FBC environments (RP589). Results obtained from this and similar ERDA projects indicate that few metals will survive very long in such service. Best results are obtained with Fe-Cr-Al alloys containing dispersed oxide phases to improve scale adhesion. The protective Al_2O_3 scales are stable at much lower oxygen activities than Cr_2O_3 scales and are not subject to loss through volatilization. Silicon is a beneficial addition in small amounts. Also, small additions of reactive elements like lanthanum greatly improve the corrosion performance of Co-Cr-W-C alloys like Stellite 6b. Erosion conditions are characterized by low particle velocities of about 18–30 m/s (60–100 ft/s) and high particle loading of several thousand ppm. However, hot corrosion and molten sulfide slags appear to be greater problems. At temperatures of 870–1090°C (1600–2000°F) and with sulfur activity above 1% H_2S, it is unlikely that any metallic material will survive, and ceramic or ceramic-lined components may have to be used.

Refractory materials under study

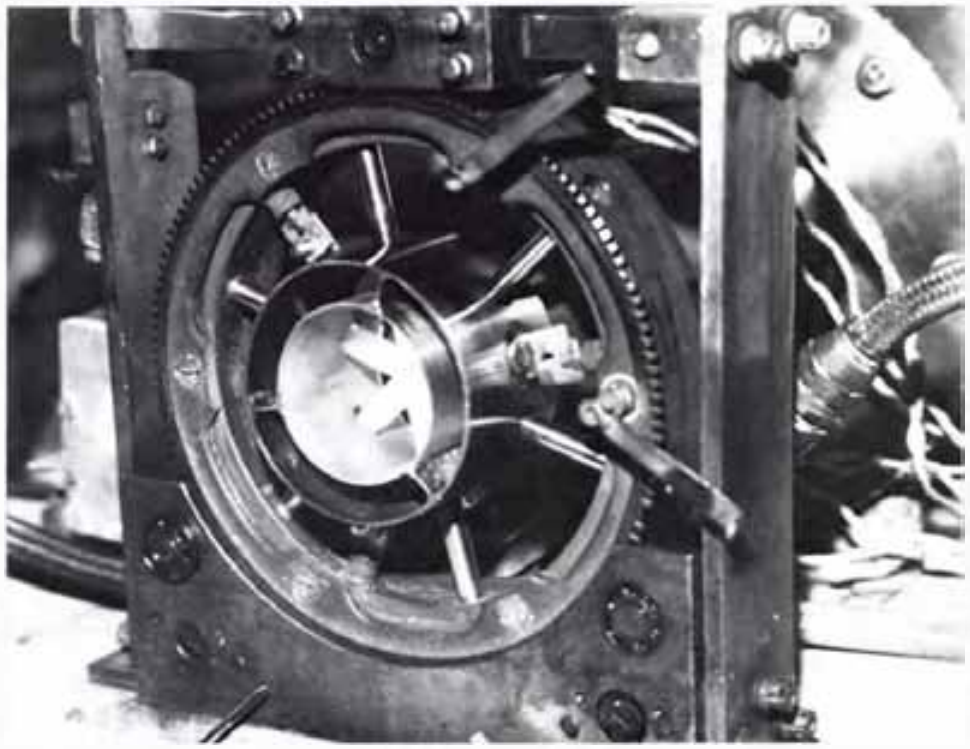
Ceramics may displace metals in coal-fired heat exchangers used with closed-cycle

turbines (RP545). The temperatures of interest to the AiResearch Division of Garrett Corp., 980–1200°C (1800–2200°F), are clearly too high for metals, and silicon carbide appears to be the ceramic of choice. Although the principal problems are designing, fabricating, and operating large, complex pieces from a brittle material, erosion and corrosion in coal-slag-laden atmospheres are also being studied. Preliminary results from burner rigs indicate that SiC is quite resistant to degradation by coal ash. A supporting study at Lockheed's Palo Alto Research Laboratory found that at the highest temperatures, slags rich in Fe_2O_3 tend to react with the free silicon in the SiC composite to form globules of molten iron. However, initial evidence from both projects suggests that such devices can probably survive slag attack for economically interesting periods of time.

Refractories for dry ash and slagging gasifiers are being studied by Westinghouse Research and Development Center, Pittsburgh (RP625). Experimental facilities consist of a fluidized bed and a pneumatic tube in which refractory specimens may be exposed to corrosion and erosion conditions similar to those expected in reactors, pneumatic transport tubes, and cyclone separators. A new model of refractory erosion, developed with data from the Westinghouse and other studies, should prove helpful in refractory development, gasifier design, and control of operating conditions to minimize erosion. Under subcontract, Harbison-Walker Refractories Division of Dresser Industries, Inc., is testing the resistance of state-of-the-art refractories to slagging conditions. From preliminary analysis it appears unlikely that any uncooled refractory will hold up to molten slags.

Corrosion and erosion of in-bed and freeboard boiler tubes in fluidized-bed boilers are major problems in FBC technology. Combustion Systems Ltd. (RP388) has run two 1000-hr tests in the 1-ft² bed operated by the Coal Research Establishment in Stoke Orchard, England. Relatively high corrosion was found in the in-bed tubes, the desired location for the superheater and reheater tubes. Much less corrosion was found in the freeboard tubes. High sulfidation rates were found for nickel-based and cobalt-based alloys, generally the backbone of high-temperature, corrosion-resistant equipment. Low-alloy ferritic steels like 2¼ Cr-1Mo were corroded more than in pulverized-coal-fired boilers; permissible temperatures for these steels will be 10–24°C (50–75°F) lower under FBC conditions. Austenitic steels performed the best. They probably will be satisfactory for use with metal temperatures up to 650°C (1200°F), which is sufficient for raising 540°C (1000°F) steam.

Figure 1 Cylindrical samples of gas turbine materials project into exhaust duct of bench-scale burner rig used by Pratt & Whitney to evaluate erosive effects of various particle loadings in hot gas stream from coal-derived fuel combustion. The spoked jig is periodically rotated so that all samples experience identical conditions



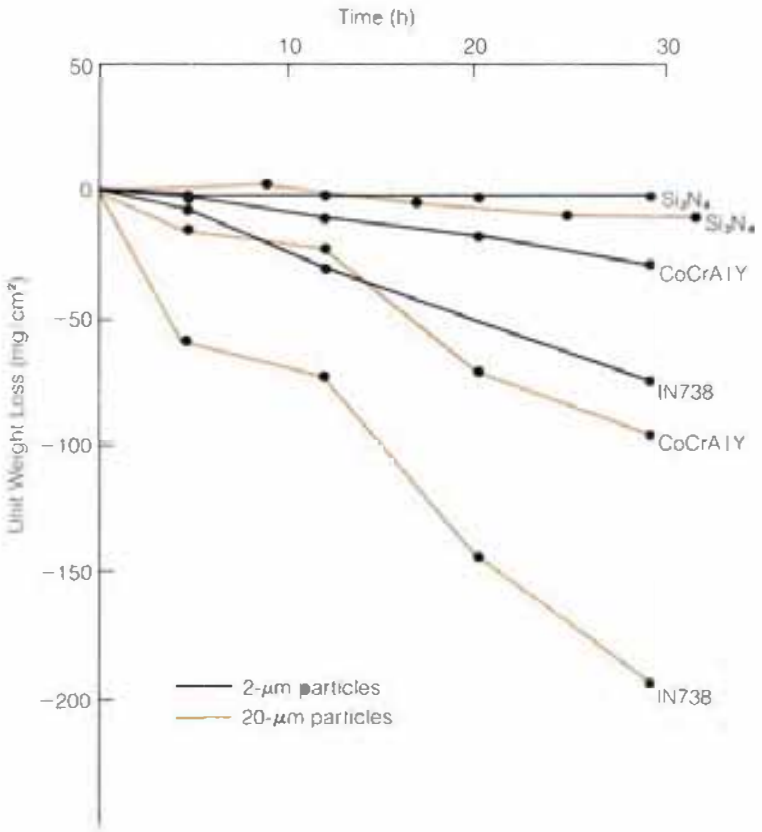
A fluidized bed apparently has relatively low oxygen activity (about 10^{-5} to 10^{-7} Pa, or 10^{-10} to 10^{-12} atm), despite the fact that considerable excess air is used. The in-bed tubes fluctuate rapidly between low and high oxygen activity. The bed temperature in the Stoke Orchard experiments was 900°C (1650°F)—somewhat higher than is desirable for optimum SO_2 removal—and a heavy calcium sulfate deposit formed around the tubes, providing sulfur for the slagging sulfidation of nickel- and cobalt-based alloys. Further experiments are planned to check the effect of lower bed temperatures and the presence of calcium-containing sorbents on FBC corrosion. The experiment will be repeated in a bed with an order-of-magnitude larger area; the small bed in the Stoke Orchard tests put the corrosion specimens close to the coal inlet ports, possibly influencing the results.

Gas turbine erosion

Production of clean fuels from coal costs both money and energy. It is therefore desirable to burn the fuels in combined-cycle plants for greater efficiency. However, particulate matter and hot corrosion contaminants may remain in the fuel, creating an erosion or a corrosion threat to the gas turbine. Pratt and Whitney Aircraft Division of United Technologies Corp. is addressing this problem (RP543). State-of-the-art turbine materials are used to evaluate a wide variety of erosion conditions (Figure 1). Hard particles like Al_2O_3 have been used for initial screening. All turbine materials were excessively eroded by 130 ppm of 20-μm Al_2O_3 particles. With the particle size reduced to 2 μm (about the size expected to pass through particulate cleanup systems), there was less (but still significant) erosion (Figure 2). A ceramic turbine material, Si_3N_4, performed remarkably well under these conditions, suggesting its consideration for industrial turbines using coal-derived fuels. Erosion resistance of alloys forming Al_2O_3 scales was greatly improved by preoxidation but not of those alloys protected by Cr_2O_3 scales. Work is now going on with softer particles, such as ash and MgO. Designers of turbines for coal-based fuels may have to walk a tightrope between erosion and fouling, neither of which is desirable.

Conversion of coal to clean solid and

Figure 2 Three materials show a wide range of weight loss under erosion by 2-μm and 20-μm particles of Al_2O_3 at 870°C (1600°F). IN738 is a nickel-based superalloy, Si_3N_4 is a ceramic structural material (which experienced a temporary weight gain, probably of SiO_2), and CoCrAlY is a physical vapor-deposited alloy coating.



liquid fuels can produce severe erosion problems in the letdown valves and slurry pumps used in the process. Battelle, Columbus Laboratories (RP458) is studying the problem and has developed an erosion wear test for valve trim materials. Cemented tungsten carbide valve trim can survive a period of weeks or months in this service. Several ceramic materials, such as B_4C and SiC, also perform well, especially B_4C. Erosion is considerably less at low angles, suggesting that long exit channels would be beneficial. The project is proving to be helpful to both letdown valve design and materials selection. *Technical Manager: Robert Jaffee*

WATER QUALITY CONTROL

EPRI's water quality control program has been established for slightly over a year. This first report identifies the major water-related problems of electric utility power plant and sets down program objectives and the initial plan for achieving them. Results from one project, begun in 1975, are reviewed.

A 1000-MW (electric) coal-fired power plant with closed-cycle evaporative cooling and stack gas scrubbing requires a water supply of 0.63–0.95 m^3/s (10,000–15,000 gpm). Accessibility of adequate water ranks with proximity of fuel supply and load center as an important siting constraint. Water-related problems can be categorized: supply, in-plant treatment, and discharge.

Supply problems involve both quantity and quality. Projections of national water supply and demand, on the basis of regions defined by the Water Resources Council, indicate that shortages for power plant use are to be expected in many areas by the year 2000. Even today, power plant requirements can lead to severe local distortion of historic water allocation patterns.

In-plant treatment requirements vary with both the quality of supply water and its intended use. Uses include power-cycle working fluid, main condenser and auxiliary cooling, flue gas scrubbing, ash sluicing and coal slurry transport, and cleaning of boiler walls, superheaters, and air-preheaters. As increased use is made of recycle, reuse, and cascaded water systems, the concentrations of impurities rise, increasing the potential for scaling and corrosion and imposing more difficult requirements on the treatment processes.

Discharge problems are largely a function of environmental regulations. Where the extreme of zero discharge is mandated (as in the Colorado River Basin), the cost of ponding, evaporation,and sludge disposal may dominate water system design. At arid western sites, lined evaporation ponds (about 64×10^6 m^2 per m^3/s, or about one acre/gpm evaporated) are estimated to cost as much as $\$12/m^2$ ($50,000 per acre). In all regions, federal limitations of "no detectable amount" on such commonly used corrosion inhibitors as zinc and chromate, and on some trace metals identified as hazardous or toxic, require costly cleanup and provide strong incentive for discharge reduction through internal recycling and subsystem integration.

In response to these conditions, EPRI water quality research is initially focused in three major project areas:

- Conservation: Reduction of "clean" water requirements with integrated water system design and use of waste water
- Process development: Advanced, economical treatment options, such as trace element removal from cleaning and sluicing waters, and corrosion and scaling control in closed-cycle cooling systems
- Discharge limitations: Modification of systems to meet discharge constraints with alternatives to chlorination for biofouling control

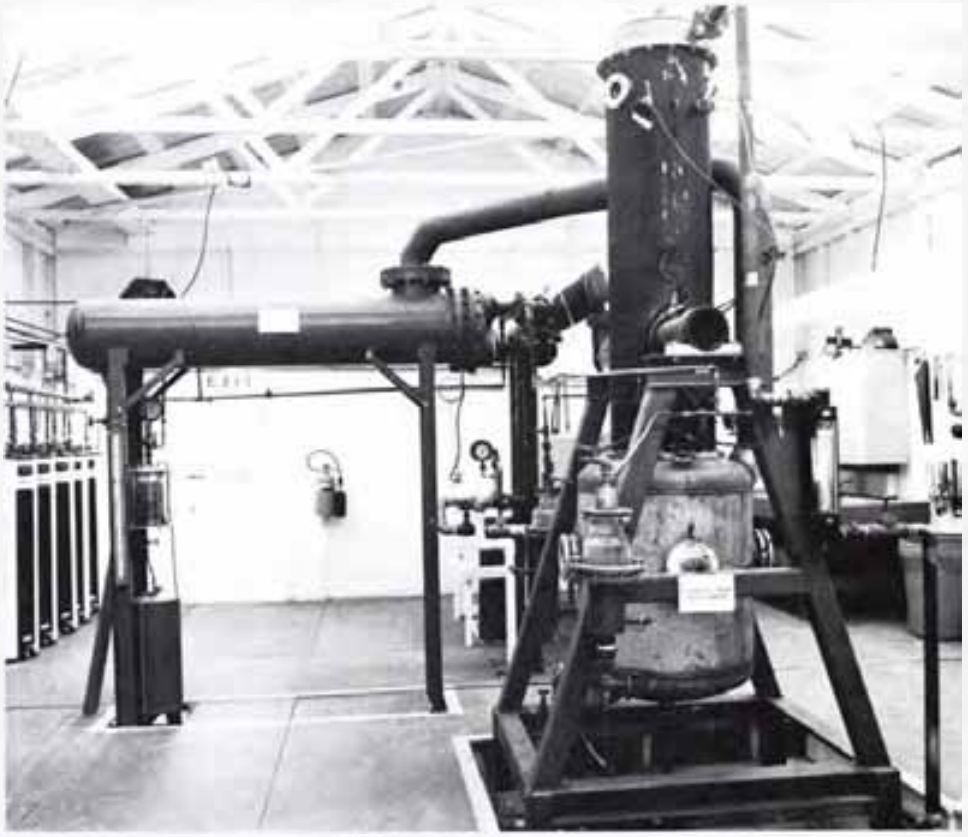
Conservation

Integrated water system design requires comprehensive descriptions of source water and coal supply characteristics, in-plant water quality needs, treatment process options, aqueous discharge constraints, and the impact of stack emission control and solid waste disposal options on water stream contamination. As these descriptions are site-dependent, the development of generalized design guidelines is a formidable task. In a project conducted by Water Purification Associates (RP909), a case study approach is being developed. Water system designs will be generated for individual plants at given locations using specified coals. The intent is not to study a composite or averaged plant but rather a range of realistic, consistent design situations encountered by utilities. Generalized procedures will then be developed from the site-specific case studies.

The basis for selecting the case studies will be established in a series of tasks that (1) define current practices and typical problem areas at several plants representing a range of climates, water qualities, coal types, and so on; (2) review the range of environmental regulations; (3) define in-plant water quality and quantity needs by subsystem; (4) identify optional flow arrangements; and (5) establish ground rules for specific integration of the water system in light of coal properties, solid residual handling and disposal, and flue gas cleanup. A sample case will then be selected and its design developed to demonstrate the effort required and results obtainable. At the conclusion of the project, it will be necessary to decide the number of cases required, the level of effort to develop the generalized guidelines, and the value to the industry of completing the study. Throughout this work, research needs will be identified in process development and in computational methods to implement integrated designs.

The use of agricultural wastewater for cooling-tower makeup is being investigated jointly by EPRI, the State of California, and three California utilities: Pacific Gas and Electric Co., Southern California Edison Co., and the Los Angeles Department of Water & Power (RP373). The project began with laboratory development work in 1975.

Figure 3 Cooling-tower blowdown is conserved in this experimental vertical tube evaporator, which uses steam and a recycled foaming agent to produce distillate (usable for steam cycle makeup) and a further concentrated stream (e.g., 70,000 mg/l, largely of Na_2SO_4) for ion-exchange regeneration of the resin for treatment of incoming cooling water.



A pilot-scale (8.7×10^{-5} m³/s, 2000 gal/d) field demonstration of an irrigation runoff treatment system is under way. Make-up water pretreatment consists of softening in an ion-exchange column. The tower blowdown, further concentrated if necessary to approach a concentration factor of ×20, is used as the regenerant for the ion-exchanger resin, thus eliminating the need for purchased regenerant and the added cost of its disposal. The system consists of the ion-exchange component, a simulated condenser—cooling-tower loop, and a foam-enhanced vertical tube evaporator (Figure 3).

Field tests aim to (1) establish design curves for the softening and regeneration unit, (2) establish limits of performance (maximum cycles of concentration) for all components, (3) demonstrate prolonged scale- and corrosion-free operation, (4) identify operating, control, and maintenance problems, and (5) provide a basis for scaling up the design and its costs for power plant application.

The project is now well along at the Firebaugh, California, test facility. Initial field results tend to confirm the majority of earlier laboratory findings:

- Steady-state operation of the softening and regeneration unit is achievable at concentrations of ×10 to ×20.
- Clogging-free operation of the ion-exchange column can be maintained by regenerating in an upflow, fluidized-bed mode.
- Concentration factors in the cooling tower alone may be sufficient to regenerate the resin, eliminating the need for the evaporator in the primary loop.
- Preliminary cost projections for a 1000-MW(electric) plant are \$0.095/m³ (\$0.36/1000 gal)—in 1976 dollars—including an-

nualized capital costs, energy input requirements, and allocated O&M charges, but excluding costs of irrigation drainage collection, silica control, or ultimate blowdown disposal.

Very recent findings indicate condenser scale formation, involving silica, and may necessitate an add-on sidestream process for silica control.

Process development

Various toxins become dissolved in water streams after entering a plant via its coal supply or as additive chemicals. For example, arsenic condensed on fly ash may dissolve in sluice water, and chromium is a common additive for corrosion control. A recently initiated project with Stanford University (RP910) is designed to determine how 10 different trace elements can be removed from fossil plant water streams by a potentially inexpensive and reliable approach—adsorption. There are three major objectives:

- Identify problem elements in the aqueous streams of fossil-fired power plants
- Establish the capabilities, limitations, and chemical process requirements for removing these elements with ferric iron
- Determine the feasibility of applying such processes to control trace elements in power plant waters

So far cadmium, arsenic, selenium, copper, zinc, and chromium have been selected for study, and most of the ideal solution work on cadmium has been completed.

Discharge limitations

Chlorine discharge from biofouling control treatments is a pressing environmental problem for many utilities that use once-through cooling. Federal effluent limitations for cooling-water discharges are an average of 0.2 mg/l free available chlorine for a maximum of 2 h/d (and as low as 0.04 mg/l total chlorine for 4 h/d at some stations). Accordingly, chlorination schedules must be altered at many plants. The impact is uncertain, however, because biofouling (in particular, its effect on heat transfer and condenser performance) is not well quantified; the biological, physical, and chemical processes that govern the buildup of the films and their destruction by biocides are poorly understood; and the alternatives to chlorination are not well developed.

Two projects are under way: a study of the fundamentals of film buildup and destruction under controlled laboratory conditions (RP902) and a pilot-scale test of ozonation at two Public Service Electric & Gas Co. plants (RP733). A third project (RP879) dealing with residual chlorine analysis standardization and instrumentation in fresh and saline water is being sponsored by the Environmental Assessment Department. *Project Manager: Roger Jorden*

GEOTHERMAL ENERGY

The main emphasis continues to be on the technology that has direct application in the development of hydrothermal resources: the Heber demonstration plant and its supporting R&D projects. Several generic (less site-specific) projects, including critical component testing, brine chemistry, and organic turbine studies, are also making significant progress.

Hydrothermal demonstration

Heber, in the Imperial Valley of California, was selected as the site because it has more of the attributes required for demonstration and because of the maturity of the reservoir assessment. The power plant will have a net capacity of 45 MW (electric) and the design will be based on the binary cycle, using an organic secondary working fluid. Construction should be complete by mid-1980.

The first phase of this project is now complete, including preliminary design and optimization studies conducted by Holt/Procon (RP580-1). Phase II, detail design and environmental report (RP580-2), will be cofunded by EPRI and a group of utilities headed by San Diego Gas & Electric Co. and including the Los Angeles Department of Water & Power, Imperial Irrigation District, and Southern California Edison Co. Other contributors are Portland General Electric Co. and Nevada Power Co. ERDA funding for construction is considered essential.

Compatibility between the reservoir and power plant control systems was the subject of one of the later studies during Phase I. Geothermal reservoirs have an inherently slow response time and are best suited to baseload operation. If several wells are supplying geothermal fluid to a single power plant, it may be impractical to regulate the flow more than ±15%, with a response time of seconds to minutes. This is too little and too slow to compensate for turbine overspeed if load were dropped, so other control schemes, such as turbine bypass and primary fluid bypass, appear likely. If the reservoir flow were to be regulated over a wider range, the response time would likely be minutes to hours for reduction in flow and hours to days for increases in flow (wells can be shut off much more quickly than they can be activated). Other optimization studies of Phase I included secondary working fluid mixtures, effects of reservoir temperature decline, and sensitivity of cost to critical operating parameters.

Heat exchange and scaling rate

Because Heber is a low-salinity, moderate-temperature hydrothermal plant using a secondary working fluid (binary) cycle, it requires service criteria for the design of brine-hydrocarbon heat exchangers. Specifically, brine-side fouling factor data will control the design allowances made for deterioration of heat transfer performance. Scaling phenomena are complex and prediction methods do not exist, so specific measurements were made during a 2000-h heat exchanger test (RP846-1) conducted by The Ben Holt Co. Objectives of the tests were threefold: confirm the 500-h test data of 1974 and extend them to 2000-h data to reduce the range of extrapolation required to predict heat exchanger service performance; develop materials selection criteria for brine heat exchanger service; and provide data to benchmark computer-based methods for scaling-rate prediction.

Drawing from the 1974 test results of San Diego Gas & Electric Co., mild carbon steel and titanium materials were evaluated for brine bulk velocities of 1.5 m/s (5 ft/s) on the tube side of a shell-and-annulus arrangement. Demineralized water, passing through the annulus side, simulated the hydrocarbon working fluid.

The specific design of the heat exchanger and the short time for conducting the scaling tests forced the simultaneous testing of both steel and titanium tubes. As the testing of both types in the same exchanger module would have led to a difficult if not impossible data reduction problem, steel tubes were tested in two of the modules and titanium tubes in the other two.

The first 500 hours of data confirm the data reported in 1974 by San Diego Gas & Electric Co. (RP376). The scale in the steel tubes is harder than that in the titanium tubes. It is layered and platelike, consisting of regions of thin and regions of thick deposits. It separates in layers and the upper layers may break away. The scale on the titanium tubes, however, appears to be much softer and more powdery in consistency. Computer methods employing standard spectra were used to analyze the X-ray spectrum and obtain quantitative estimates of scale composition. Results indicate (Table

Table 1
COMPOSITION OF HEBER HEAT EXCHANGER SCALE
(values in at%)

Tube material	Ti	Ti	Steel	Steel	Steel
Temperature	56°C (132°F)	84°C (183°F)	66°C (150°F)	116°C (240°F)	173°C (343°F)
Element					
S	42.7*	49.2*	47.1	34.0	21.0
Sb	33.0*	31.5*	7.7	4.0	7.4
Fe	0.7	2.4	19.5	29.4	46.5
Si	19.5	10.1	23.4	11.2	5.6
As	2.1	3.6	0.7	1.9	9.3
Zn	0.4	0.8	1.0	10.0	5.4
Pb	0.2	2.4	0.2	Trace	0.1
Sn	0.2	Trace	Trace	0.2	Trace
Th	1.2	Trace	Trace	0.2	Trace
Ca	—	—	—	9.3	4.8
Total	100.0	100.0	99.6	100.2	100.1

*Probably in the form Sb_2S_3.

1) that iron and silica are important on the steel tubes, but that sulfur is also very important, with zinc and antimony present in smaller concentrations. On the titanium tubes, sulfur and antimony are the major constituents, with silicon present in significant quantities as well.

With respect to corrosion, the mild carbon steel appears to corrode at the rate of 0.5% by weight per year. However, the iron is equally dispersed throughout the scale, suggesting either that the iron corrosion product migrates away from the surface or that iron is attracted from the brine. In either case, neither the exposed mild carbon steel nor the unexposed control mild carbon steel exhibits pitting corrosion. Hence, it appears that mild carbon steel cannot be eliminated on the basis of corrosion.

Hydrocarbon turbine studies

The Heber plant binary cycle will utilize a turbine generator set that will develop 65 MW (electric) gross output. Because such large single hydrocarbon turbines have not previously been built, preliminary design studies for two competing turbine types have been funded: RP928-1, with Elliott Co., concerns the axial flow turbine concept, and RP928-3, with Rotoflow Corp., focuses on the radial flow turbine concept.

Objectives of the turbine studies are threefold.

- Focus on preliminary design of a turbine appropriate for the Heber plant (specific hydrocarbon working fluids and specific turbine inlet and exhaust conditions)
- Investigate the suitability of that turbine design over a range of turbine requirements represented by different geothermal brine types
- Investigate the sensitivity of the design to possible environmental conditions (through changes in condenser conditions prompted by changes in either wet-bulb or dry-bulb temperatures), including gradual thermal and fluids production decline of a geothermal field

The axial flow turbine design is a 3600-rpm, double-entry, three-stage machine employing a last-stage rotor diameter of 711.2 mm (28 in) and last-row blade height of 202.8 mm (8 in). The inlet gas flange of 762 mm diameter (30 in) maintains gas velocity below 30.5 m/s (100 ft/s). It will produce about 65 MW (electric) gross at 84% overall efficiency, with a generator power factor and efficiency of 90% and 98%, respectively. The working fluid is a mixture of 80 mol % isobutane and 20 mol % isopentane with throttle valve exit conditions of 140°C and 3100 × 10^3 Pa (283°F, 450 psia), and exhaust flange conditions of 70°C and 496 × 10^3 Pa (157°F, 72 psia).

The radial flow machine will probably be a three-wheel machine housed in two casings, one double-entry casing and one single-entry. Adjustable nozzles will maintain machine performance with variation of working fluid flow rate at design throttle conditions of pressure and temperature. The same working fluid mixtures will be assumed with the same throttle valve and exhaust conditions as used for the axial flow machine.

Control systems will require some extrapolation for size scale-up. For both turbine concepts, the response times required of the control systems will have to be considerably faster than required for steam turbines. The higher molecular weight of the working fluid, coupled with the smaller rotor-blade masses, requires trip valve actuation times of 0.1–0.3 s.

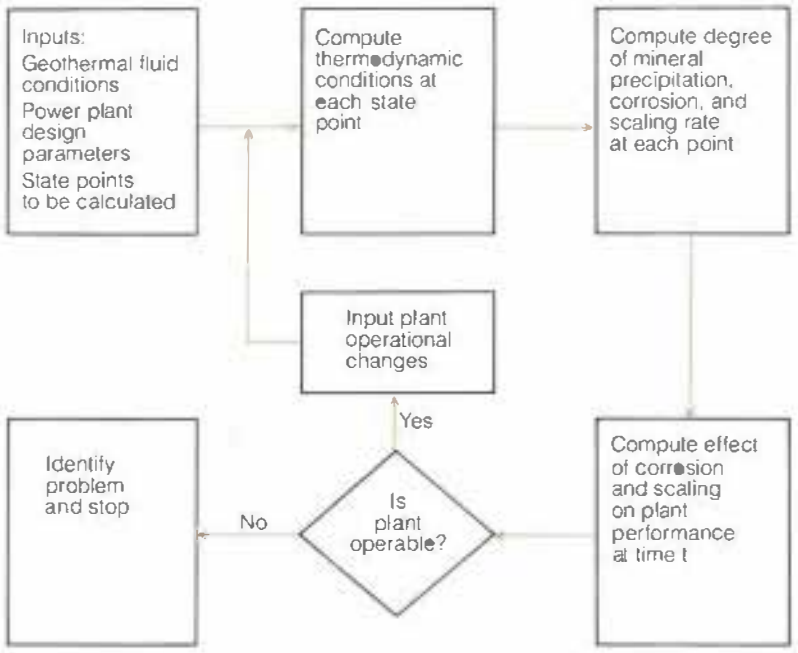
Other specific study results include estimates of turbine generator costs and delivery times and of O&M costs. Assessments of reliability, maintainability, and maintenance schedules are being made, along with procedures for startup loading, including loading rate. These data will be important for the design of working fluid loops that take appropriate account of operations problems.

Brine chemistry and heat-mass transfer

A significant portion of geothermal resources in the U.S. (other than the steam field at The Geysers) are liquid-dominated. Each system contains water that has been in contact and in chemical equilibrium with a unique set of rocks. Thus, the fluid of each geothermal system will exhibit unique chemical properties.

A capability is needed for evaluating the changing chemistry and solubility of geothermal fluids as a function of time as they pass through the power plant. This problem is even more complex because much of the basic information must be developed through analytic techniques, laboratory tests, and field measurements. Battelle, Pacific Northwest Laboratories, has just completed a 15-month effort to develop basic predictive techniques (RP653). Preliminary results indicate that most prior analyses of geothermal brines are suspect and many are deficient. A computer program using chemical equilibrium information for 131 mineral species has been developed, permitting calculation of the equilibrium chemical concentrations in geothermal brines as a function of temperature and pH. Scaling kinetics experiments of calcium carbonate and silica-rich brines have yielded results that agree with those calculated by

Figure 4 In this heat-mass transfer model, the effects of scaling on geothermal power plant operation can be calculated and evaluated, providing insight into operating and maintenance strategies and their associated costs.



the computer program and field tests.

Figure 4 is a simplified schematic of the computer model being developed. The user of the program can select or specify plant configuration, operating parameters, and geothermal brine chemistry and physical properties that best fit the particular case to be analyzed. The first step in the model is to develop the plant configuration. The model then calculates the basic thermodynamic and operational characteristics of up to 140 state points at various locations in the fluid flow path. Changing thermodynamic conditions determine the number of state points.

At each successive thermodynamic state point, the model refers to the equilibrium chemistry model to calculate the change in equilibrium concentration of the various chemical species once flow has started. Supersaturation becomes the driving force for precipitation of some chemical species. The scaling rate is a function of supersaturation and allows the calculation of scale deposited at each state point during each time interval. The computer program simulates plant operation for a specified time interval or until some problem is flagged.

Knowledge of the equilibrium chemistry and of the kinetics of scaling from geothermal brine solutions is the most important input in calculating the time-dependent heat and mass transfer of geothermal power plants. Battelle built on the available data base and made several significant changes so that the equilibrium concentrations of mineral species can be calculated over the expected range of pH, temperature, and redox potential. These improvements allow determination of the species and amount of material that can precipitate from brine solutions.

At the start of RP653 little published information existed on the kinetics of scaling of geothermal brines. Therefore, an experimental scaling kinetics facility was built in which to model the components that exist where key thermodynamic and hydrodynamic changes occur in a power plant (e.g., binary heat exchangers, flash separators, condensers, piping, and so on). Initial experiments were directed toward scaling kinetics of silica and calcium carbonate solutions, the most common scales from geothermal brines. Results of chemical analysis of the scales and brine have shown significant agreement with the equilibrium chemistry model calculations. Table 2 compares results for a calcium carbonate–sodium chloride brine solution that flashes to steam plus brine at 169°C (336°F). The kinetic part of the experiments shows that calcite precipitates immediately upon loss of CO_2 pressure but that the scaling on plant components proceeds at a much slower rate. The latter results are incomplete.

Another important part of RP653 is comparison of the experimental results and equilibrium chemical model predictions with scaling and corrosion observed to occur on power plant components at geothermal fields. Agreement is necessary in order to have confidence in the model results. Table 2 figures are from a simplified chemical model of the East Mesa geothermal brine. Results of the model calculation agree fairly well with the experimental determinations. A much more important correlation—from a more complicated real chemical system—was obtained from preliminary analysis of the scale formed during the 2000-h heat exchanger test at Heber.

Table 3 lists the analysis of the scale formed on the mild steel heat exchanger tubes at 116°C (240°F) and the predicted scale phases. The comparative data show good qualitative agreement. In this case the geothermal well was self-flowing. The brine flashed to a few percent steam in the well, and its actual condition in the heat exchanger was very near the saturation curve. In the liquid phase, the predicted scale is quartz (SiO_2) and pyrite (FeS_2); if partially flashed, the predicted scale is calcite ($CaCO_3$), quartz (SiO_2), and minnesotite ($Fe_3Si_4O_{10}(OH)_2$). The observed scale is rich in iron, silica, sulfur, and calcium (this agrees with the prediction) as well as in antimony and zinc. Antimony is not yet in the computer data base but is expected to have a chemical reaction similar to that of iron; the high zinc concentration is not yet explained.

The agreement between field observations and calculations gives confidence that the general approach will produce useful results for utilities wishing to evaluate heat and mass transfer in geothermal brine systems. Significant additional work is required, especially in the kinetics of scale information.

Program Manager: Vasel Roberts

Table 2
SIMPLIFIED EAST MESA GEOTHERMAL BRINE CHEMISTRY MODEL
(0.1 *M* NaCl solution [5845 mg/l])

	Chemical Model Predicted Value	*Experimental Value*
Initial conditions		
Temperature	25°C	20°C
Total pressure (Pa)	4.13×10^5	4.14×10^5
pH	4.5	5.2
Total Ca^{++}(*M*)	1.4986×10^{-3}	1.97×10^{-3}
Total CO_2 (*M*)	0.16	0.05
Conditions at elevated temperature		
Temperature	169°C	169°C
Total pressure (Pa)	15.47×10^5	22.61×10^5
pH	5.2 at 169°C	5.3 at 20°C*
Total Ca^{++} (*M*)	1.4988×10^{-3}	2.47×10^{-3}
Total CO_2 (*M*)	0.07385	0.062
% Ca precipitated	None	None
Conditions after CO_2 pressure release		
Temperature	163°C	162°C
Total pressure (Pa)	6.51×10^5	5.93×10^5
pH	7.6 at 163°C	6.14 at 20°C*
Total Ca^{++} (*M*)	4.892×10^{-4}	1.7×10^{-3}
Total CO_2 (*M*)	4.892×10^{-4}	6.04×10^{-3}
% Ca precipitated	33%	69%

*pH cannot be measured at elevated temperature.

Table 3
COMPARATIVE ANALYSIS OF HEBER HEAT EXCHANGER SCALE
(mild steel tubes at 116°C)

Observation		*Calculation**	
Element	*%*	*Without Flashing*	*Partial Flashing (to 172 × 10^3 Pa absolute)*
S	34.0	SiO_2	$CaCO_3$
Sb	4.0	FeS_2	SiO_2
Fe	29.4		$Fe_3Si_4O_{10}(OH)_2$
Si	11.2		
As	1.9		
Zn	10.0		
Sn	0.2		
Th	0.2		
Ca	9.3		

*Based on the equilibrium chemistry code.

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

ADVANCED ACOUSTIC TESTING TECHNIQUES

During the past few years there has been an accelerated growth in the scope of preservice and in-service inspection of nuclear reactor systems and in the requirements governing inspection. The increased interest of the utility industry and the increased requirements of regulatory bodies have resulted in greatly expanded research efforts in nondestructive testing. These expanded efforts in the field of ultrasonic flaw-imaging techniques are expected to enhance the ability to find, size, and classify flaws in both pressure vessels and austenitic stainless steel piping.

Limited field applications are starting this year. The basis for more widespread application and for use in code cases in the 1978–1979 period is being developed.

EPRI has made two significant advances in the art of ultrasonic inspection of the nuclear pressure boundary. When reduced to field practice, these research efforts promise to bring about substantial improvements in the finding and sizing of flaws in thick-clad steel vessels and stainless steel piping.

Ultrasonic holography

Specific criteria have been developed in fracture mechanics for establishing the severity of flaws in pressure vessel structures. The 1974 addenda to Section XI of the ASME Boiler and Pressure Vessel Code describe the procedures to be followed in this type of analysis (*1*). The sizing criteria for flaws located in various areas of the heavy section member are treated differently. The "a" and "l" dimensions (major axis and minor axis, respectively, of an ellipse circling the flaw) take on special significance.

Present ultrasonic procedures, as established by ASME Section XI, are sometimes ambiguous in the information they provide about the dimensions and the type of flaw, both of which are important for evaluating flaw severity. Acoustic holography (*2, 3*) shows great promise for providing this information accurately.

The objective of the current project, being performed by Babcock & Wilcox Co. (RP 605), is to determine the ability of ultrasonic holography to characterize defects accurately, that is, to describe size, shape, orientation, location, and type of defects in thick-section materials. To evaluate the capability of holography, it is necessary to correlate its results with those from conventional nondestructive testing (NDT) and with those from destructive examination.

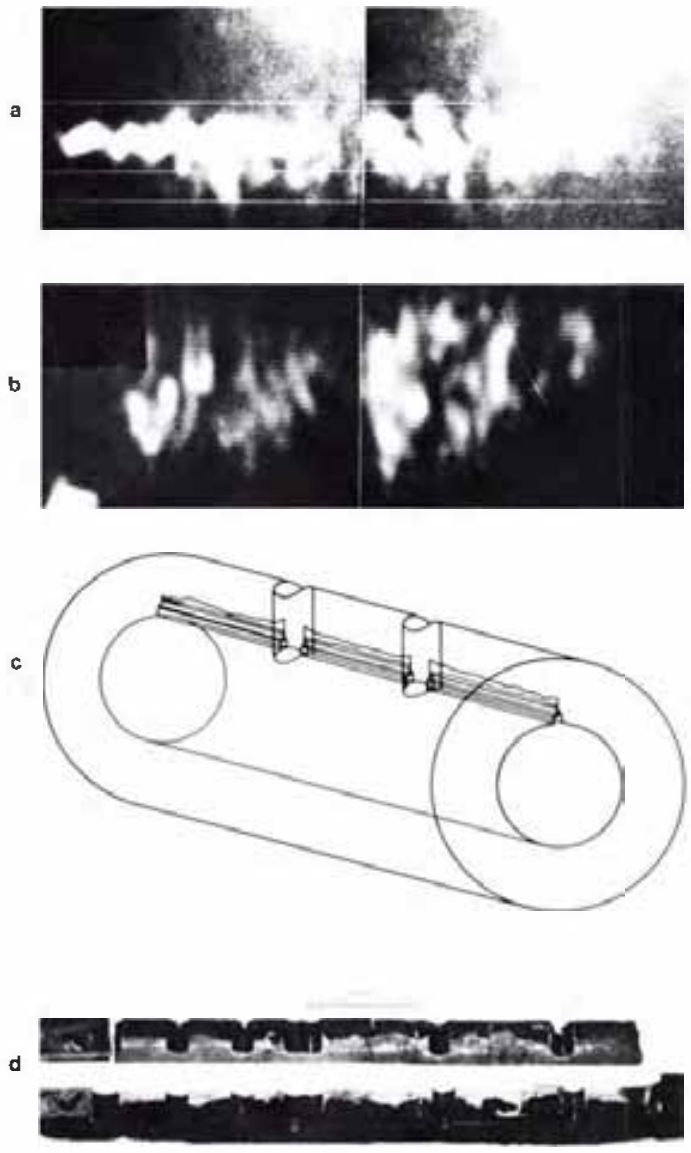
In previous projects it was shown that the use of conventional test blocks with side-drilled or flat-bottomed holes is not adequate to demonstrate the advantages of holography over conventional techniques. Generating images of natural flaws in production-lot components and comparing these images with the interpretation of conventional NDT results is a requirement for defining the benefits of holography. Therefore, naturally occurring defects in production vessels that have been judged repairable and weld defects occurring in special experimental vessels will be holographically imaged. In some cases, the imaging will be conducted from a clad surface. In addition to the naturally occurring defects, defects intentionally produced in the welds of the nonproduction vessels will be imaged.

Because many of the components on which acoustic holography is to be performed present curved surfaces, the effect of surface curvature on image quality will be investigated. To ensure that the full capabilities of acoustic holography are exploited, the holographic system will be modified to secure optimal performance during data acquisition on production components. This is of particular importance when adapting the commercially available holographic system to the examination of components with complex surface curvature.

Four naturally occurring defects have been imaged in production welds. In all cases, these defects were later destructively analyzed during removal by arc air methods. The defects were photographed and measured as they were exposed during removal. Ultrasonic examinations that met the requirements of ASME Section XI were performed on one of these defects. On the other three defects, ultrasonic examinations were performed that did not conform to the requirements of Section XI. A number of additional defects in production vessels will probably be imaged. Independent in-service inspection teams may conduct Section XI ultrasonic examination on some of these weld defects prior to either acoustic holographic imaging or destructive analysis.

During the past few months, two heavy-section steel technology thermal shock vessels (*4*) were examined in detail by acoustic holography. In both vessels, cracks were initiated and propagated by thermal shock. Acoustic holographic images were made beforehand for comparison with images obtained after propagation of the crack by thermal shock. Figures 1a and 1b are holograms of an isolated area of one crack before thermal shock and of the extended crack after thermal shock. An artist's reconstruction of what was found during destructive examination of the vessel is shown in Figure 1c. The results shown were derived from holographic information and clearly identify the amount of crack propagation during thermal shock. Figure 1c is not a scale drawing. The vessel is 1 m (3 ft) long with a wall thickness of 15 cm (5.75 in). Using acoustic holography, the crack depth from the inner surface of the wall was measured every 10 cm (4 in) along the length. Corresponding data during destructive examination are shown in Figure 1d. The excellent comparison between the destructive examination and the holographic imaging can be seen. However, additional core samples taken

Figure 1 Examination of a crack front by acoustic holography. Figure 1a shows hologram before thermal shock; 1b, hologram after thermal shock; 1c, artist's reconstruction of the crack front obtained from holographic imaging; 1d, the crack as seen after destructive examination of the vessel, permitting comparison with the holograms.



after the nondestructive examination complicate the visual comparison.

The holographic data obtained from the second thermal shock test are now undergoing analysis. Although incomplete at this time, the analysis indicates that crack propagation during thermal shock was about the same as on the first vessel test.

Because acoustic holographic imaging still depends on the reflection of ultrasonic energy from the defect, it may not be possible to image extremely tight cracks with high accuracy. On the first thermal shock vessel, acoustic holography indicated a maximum crack propagation of 4 cm (1.55 in). Destructive examination indicated a maximum growth of 4.3 cm (1.7 in). Acoustic holography, however, did indicate positions where maximum and minimum crack propagation occurred. More work to qualify this effect is needed.

Real-time flaw-imaging device

The application of acoustic holography to the examination of pressure vessels is relatively new. Because of the nature of commercial equipment, these examinations are slow and not adequate for volumetric inspection of pressure vessel welds. EPRI has therefore initiated research with Battelle, Pacific Northwest Laboratories and Holosonics, Inc. (RP606) to develop a new type of ultrasonic imaging system (*5*). The research is designed to combine the advantages of pulse-echo inspection with those of holographic inspection to provide a near real time ultrasonic image of reflectors (flaws) in the weld zone of the reactor pressure vessel.

The system is built around the use of a linear ultrasonic array for use in both the pulse-echo and holographic modes. The system consists of a host computer that controls all functions in the system, a mechanical scanning bridge that manipulates the ultrasonic array, and a pulse-echo flaw detector that can provide A-scan information and can project an isometric image of the weld volume being scanned. The isometric image is a combined B- and C-scan projection showing the reflectors detected by the pulse-echo system in their proper perspective with respect to location within the volume.

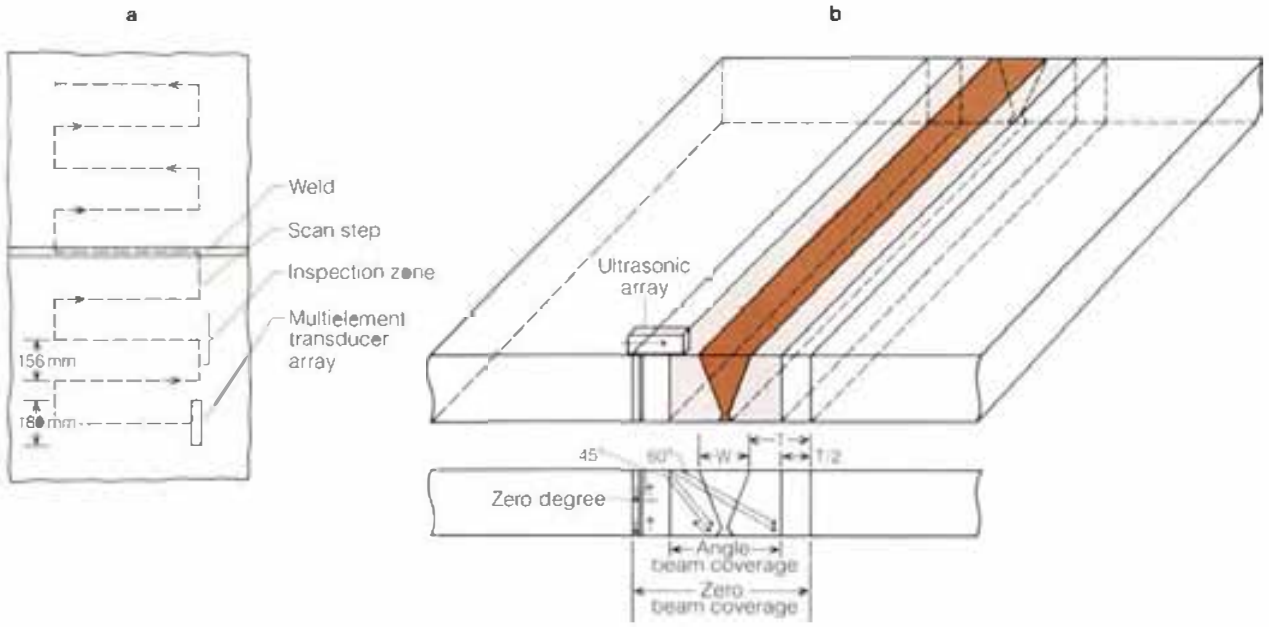
Once a suspect area is located, the system is shifted to a holographic operation and a hologram or series of holograms is taken for detailed analysis of the character of the reflector. The holographic system has two monitors—one recording the holographic image and another providing a reconstruction of the hologram for direct viewing or archival storage.

The mechanical system is designed to provide x and y mechanical translation and to provide exact coordinate information that can be used by the computer and the remainder of the electronic system to locate the array and the sound beam projected from the array. The mechanical system is attached to a fixed carriage located inside the reactor containment. The array will contact the surface of the vessel and use a positive pressure water-gap technique for coupling the sound energy. The system is designed to cover about 0.75 m^2/min (4 ft^2/min). This will provide a pulse-echo scanning rate of 0.3 m/min (1 ft/min).

The sound beam projected from the array is sequentially pulsed and the number of elements and the sequence series is selected by the computer. To obtain a 0° sound field, each of the individual elements of the array is pulsed simultaneously. To obtain an angle beam from the array, the time of pulsing of the individual elements in the array is changed by a fixed amount, resulting in a phasing of the energy and causing the beam to steer to a selected position.

The array is moved back and forth across

Figure 2 A new type of ultrasonic imaging system. Figure 2a shows the movement pattern of the linear ultrasonic array; 2b, the array positioning for 0°, 45°, and 60° angle beam inspection.



the weld volume in an orthogonal pattern (Figure 2a). While we are interested only in the weld volume, for inspection at such angles as 60° the array must be moved a substantial distance from the centerline of the weld. The scanning pattern may be chosen to follow across the weld or along manual control of the position of the array.

The inspection procedure is complex (Figure 2b). The array is moved along the weld and indexed across the weld. The mechanical position of the array starts at the longest sound beam (the 60° beam, looking into the weld). In the pulse-echo mode, the 0°, 45°, and 60° angle beam inspections are developed sequentially. As the array moves across the surface, the 0° inspection is followed by the 45° inspection, which in turn is followed by the 60° inspection. As each sweep across the array requires only a few milliseconds, the mechanical speed of the array can be chosen to achieve an overlap of the sound beams from the array. The information from the 0°, 45°, and 60° inspections is superimposed on the isometric image for viewing by the operator. As the array crosses the centerline of the weld, the angle beam inspections are reversed for observation of the

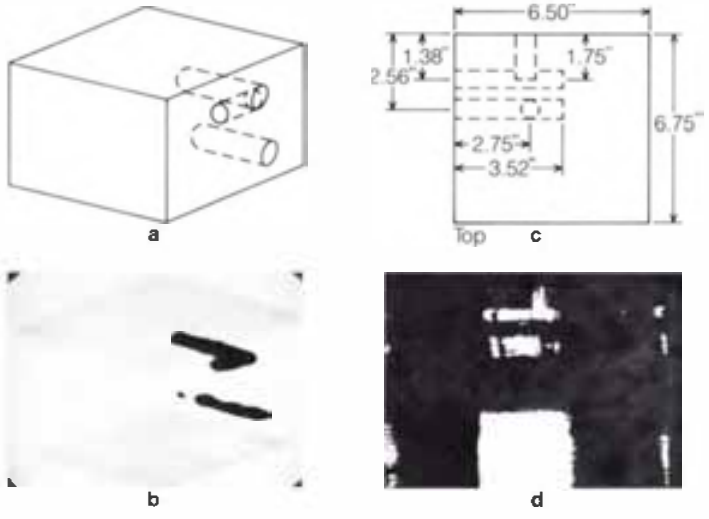


Figure 3 The pulse-echo information from the ultrasonic array in Figure 2 is displayed isometrically. The isometric sketch is shown in 3a; the ultrasonic image, in 3b; the potential for this inspection mode, in 3c and 3d (which show the actual positions and dimensions of holes in a test block and how it is possible to reconstruct the plan by holography).

opposite side of the weld, providing full volumetric examination from a single scan across the inspected area. The pulse-echo mode is designed for high-speed search and locating. The holographic mode is designed for detailed characterization and recording of specific information in the weld zone.

The system has been under development for about one year, and initial results have been obtained in both the pulse-echo and holographic inspection modes. The pulse-echo information is designed to be displayed on an isometric display system (Figure 3a). The isometric display provides the operator with a volume view of approximately 0.6 m (2 ft) of weld zone. The flaw information is gated to record only the signals from the weld zone. The computer supplies the coordinate information and the angle beam location of the sound field so that by combining them on the display monitor a full view is given of all the inspection modes.

The image (Figure 3b) was generated from a 20 × 20 cm (8 × 8 in) block of material containing side-drilled holes. The front and rear surfaces have been gray-scale-suppressed to ensure that subsurface flaws are not masked by the surface signal. The system records direct reflections seen by the examination and provides a rear-surface record, which gives additional detail to describe the character of the flaw. In the instance shown, the location of the side-drilled hole is not apparent from the direct image (or the line sketch). However, the rear-surface information clearly shows that the hole has been drilled from the rear of the block (Figure 3c).

The hologram (Figure 3d) is of a test object with a series of side-drilled holes located at different depths and in different positions. It shows some of the potential for this inspection mode. The large white area is the zero-order information and should be disregarded. The reconstruction of the side-drilled holes shows two of the holes in focus—those projected from the left and rear sides of the block. It shows the deeper hole out of focus, as should be expected from the holographic reconstruction, but more important, it shows the end-drilled, round-bottomed hole in its correct size and location.

The pulse-echo and holographic results are preliminary. The system is still at a breadboard stage but shows promise. We hope to be able to make a hologram and provide a real-time reconstructed view in 5–10 s per hologram. A laboratory demonstration model of the complete system will be available in late 1977. An improved prototype capable of field inspection will be available late in 1979. *Program Manager: Karl Stahlkopf*

REACTOR TRANSIENT DATA

In conjunction with its various computer code development programs, EPRI is sponsoring a number of experimental projects aimed at obtaining reference quality (benchmark) data from operating power reactors for use in the qualification of these computer codes. It is well recognized that power reactors are not experimental devices. Yet no experimental facilities in existence can simulate adequately the response of a 3300-MW (thermal) BWR to modest pressure oscillations and transients. Such oscillations and transients, although not routine or frequent, are expected to occur a number of times during the operating life of a plant and have been shown to constitute no safety hazard. To accumulate further proof of this, measurements can be made that will qualify calculation methods. Such measurements must not only be planned with care but must also be carried out with close review by the NRC.

A current project that involves measurements at the Peach Bottom-2 BWR of Philadelphia Electric Co. is an example (RP1020). This project, jointly sponsored by EPRI and the General Electric Co., has these objectives:

- Measure the transient response of the BWR core power and other important reactor process signals during a rapid pressurization transient resulting from a sudden rejection of turbine load at less than full power operating conditions (test point TT1–TT3 in Figure 4)

- Measure the BWR core response characteristics by testing with small pressure step changes to evaluate stability at high power-flow ratios at less than full power operating

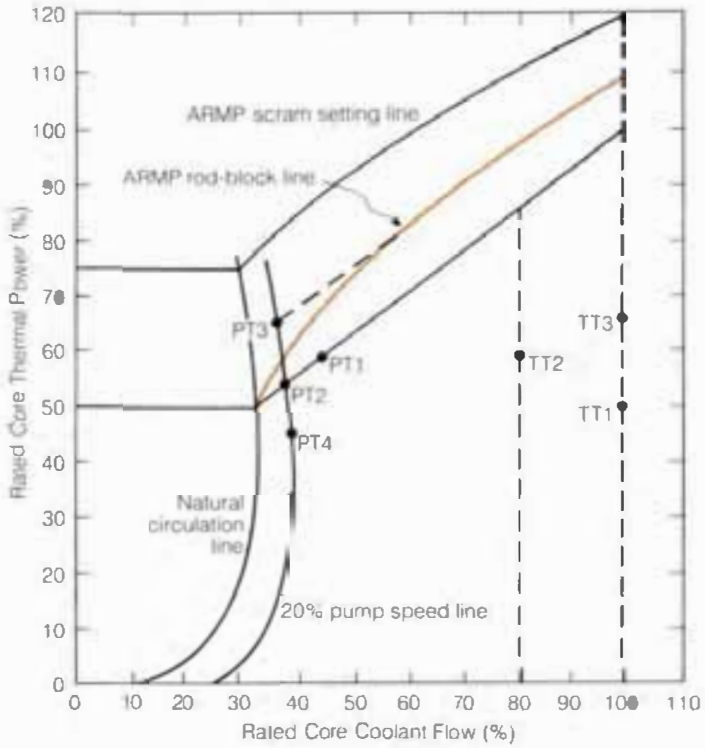


Figure 4 The power map for Peach Bottom-2 (the chart of core thermal power versus core coolant flow). The rod-block power–flow line (in color) represents the points for any combination of coolant flow and core power at which any further withdrawal of control rods (to increase power) is automatically blocked. The 20% pump speed line shows power-flow conditions when the recirculation pumps are running at 20% of rated speed.

conditions (test points PT1-PT4 in Figure 4)

Although the planning for this project was begun in the fall of 1976, a great deal of preparatory work was required. Special instrumentation and cabling were installed at the reactor site. Data acquisition equipment and data reduction programs were installed and checked. The temporary changes in the reactor technical specifications needed to permit stability testing above the rod-block power–flow line (Figure 4) were prepared, checked, and approved. Pretest predictions of the transient decay ratio and neutron flux spikes expected during the pressurization transient were performed and analyzed. As a result of close coordination between the NRC, Philadelphia Electric, General Electric, and EPRI, all was ready as Peach Bottom-2 neared the end of its second fuel cycle in April.

The test program was executed without major difficulty. Three pressurization transients were performed from power levels ranging from 50% to 70% of rated power. The coupling from pressure rise to neutron flux was measured by allowing the reactor to be scrammed by the high-flux signal instead of the normal anticipatory scram signal on closure of the turbine stop valves. Care was taken to ensure that fuel preconditioning envelopes were not violated. Four stability tests were conducted by making small changes in the pressure-regulator set point at points along the 20% recirculation-pump speed line (Figure 4). More than 100 process signals were sampled every 6 ms, digitized, and recorded on magnetic tape in each test.

Data reduction and analysis will take place this summer. Work will begin on the development of RETRAN and MEKIN models of the Peach Bottom nuclear steam supply system so that predictions may be made with these computer codes for comparison with the experimental data. *Project Manager: Robert N. Whitesel*

REACTOR POWER DISTRIBUTION DATA

Another EPRI experimental project to gather reference quality data from operating power reactors for computer code qualification is now nearing completion (RP130). General Electric Co. is using gamma-scanning techniques during a refueling outage to measure the distribution of reactor power that existed just before reactor shutdown.

The measurements should provide power distribution information from most or all of the fuel bundles in a large sector of the reactor core, usually an octant. When these data are combined with measurements from a number of symmetrically located fuel assemblies, important information on reactor core performance can be derived. Moreover, such power distribution information presents a challenge to the capability of fuel management calculation systems. EPRI's principal goal in gathering these data has been to provide tests for the ARMP computer code package.

Three gamma-scan campaigns have been completed. A report has been published on the first of these (*6*); the other two are currently in the data reduction stage.

In January 1976, gamma-scan measurements were performed after cycle 2 at the Quad Cities-1 BWR of Commonwealth Edison Co. Measurements of the axial power shape were made on 71 uranium dioxide fuel bundles in an octant of the core, as well as on the 5 mixed uranium–plutonium dioxide assemblies (RP497, Quad Cities-1 nuclear and fuel performance measurements with plutonium recycle bundles).

In addition, 5 assemblies (2 mixed oxide and 3 uranium dioxide) were disassembled and scanned rod by rod to measure local power variation within the bundles. A report on the Quad Cities gamma scans (NP-214) was published late in 1976 (*6*). One of the reports from RP497 (*7*) contains design and operating data from the first two cycles of operation of Quad Cities-1. Using this information, a project with Nuclear Associates International, Inc. recently started testing the ability of the ARMP codes to predict the measured power distributions (RP973). The second of the scans was completed after cycle 1 at the Zion-2 PWR, which is owned and operated by Commonwealth Edison Co. Again, the bundles in an octant of the core were scanned for axial power distribution. No local power variation measurements were possible as the PWR bundles cannot be readily disassembled. The experimental data have now been reduced. Efforts are also under way to document sufficient design and operating data for Zion-2 so that ARMP calculations can be performed for comparison with Zion-2 gamma scans.

The third and final measurement campaign was completed after cycle 1 at the Hatch-1 BWR, owned and operated by Georgia Power Co. The measurements were conducted in a manner similar to that used at Quad Cities-1. The principal achievement of the Hatch scans was to obtain power distribution data from a reactor with a fixed and substantial control-rod inventory at the end of the cycle. (As Quad Cities-1 approached the end of cycle 2, it was operated in an all-rods-out configuration.) A total of 106 assemblies were axially scanned; 4 bundles were disassembled for rod-by-rod measurements. Data reduction is now in progress. *Project Manager: Robert N. Whitesel*

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Evaluating the Performance of In-Service Inspectors

by Eugene R. Reinhart

An EPRI study evaluating current practice for in-service inspection of reactor piping and pipe welds shows the way to even better techniques for detection of potential flaws.

▫ An EPRI technical article

Beginning in late 1974, intergranular cracks were detected in the stainless steel recirculation bypass piping and core spray piping of several operating BWR nuclear plants (*1*). The detection methods included leakage monitoring systems and a combination of such in-service nondestructive evaluation (NDE) techniques as visual inspection (VI), ultrasonic testing (UT), dye penetrant testing (DPT), and radiographic testing (RT) (*2*). Metallurgical examination and laboratory tests of cracked pipes removed from these plants indicated that the cracking was caused by an intergranular stress corrosion mechanism. Such a mechanism results from a complex interaction among stress (including fabrication and duty-related stress), sensitization, and an oxygenated high-purity aqueous environment (*3, 4*).

Metallurgical examinations have shown that nearly all such cracks are found in the heat-affected zone on the inside surface of the pipe, adjacent to a weld and usually parallel to the weld plane. In some cases, near the location at which stress corrosion cracks can occur, the inside surface of the pipe shows significant changes in section as a result of fabrication procedures (pipe counterbore and grinding marks) and weld irregularities (such as drop through and mismatch) (*2*). These geometric changes in section act as reflectors for sound waves, causing confusing interferences for ultrasonic inspection.

The geometric reflectors tend to mask the ultrasonic reflections from possible cracks to the extent that multiple observations and careful, time-consuming analysis must be used to distinguish the crack reflections from the geometric signals. Also, intergranular stress corrosion cracks tend to follow the grain boundaries in the material and therefore present an irregular, diffuse reflection surface for ultrasonic energy. Compared to an equivalent-sized planar fatigue crack on which present techniques are based, intergranular stress corrosion cracking provides a confusing and low-amplitude ultrasonic response relative to typical drilled holes or machined notches, which are used as calibration reflectors (Figure 1). Also, such cracks usually show little or no gap between the crack surfaces. This condition also tends to minimize ultrasonic response from a flaw due to reduced impedance mismatch of the surfaces; sound passes through the surfaces and does not reflect. These characteristics of stress corrosion cracks further compound the inspection problem because they allow less margin for error in calibration sensitivity, inspection procedure, and operator interpretation of derived ultrasonic signals.

Present in-service inspection practice as required by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, uses pulse-echo ultrasonics to detect and define the nature of flaws in primary system piping (*4*). This technique is presently the most appropriate volumetric inspection method available. However, prior work has not included a full evaluation of its detection probabilities for intergranular stress corrosion cracking as found in BWR piping.

To achieve the best possible inspection, it is necessary to know how efficiently various techniques of in-service inspection detect the degree of penetration of intergranular stress corrosion cracks. Through-wall penetration of these flaws during operation is not regarded as a critical safety issue, since the containment design of the plant is based on the assumption of large leaks from piping. However, on several occasions the Nuclear Regulatory Commission has mandated special inspections, which caused outages of from one to three weeks. Also, it is highly desirable, whenever possible, to detect and repair such cracks before they leak to avoid the considerable loss in plant availability when repair and cleanup operations require plant shutdown. Questions raised by the NRC made it evident that the present range of ultrasonic inspection practices should be extensively evaluated to define limitations and to permit sharp definition of areas needing improvement.

To define the ability of present ultrasonic and radiographic methods to detect stress corrosion cracks, EPRI's staff carried out a project that included a round-robin evaluation of cracked and uncracked pipe samples examined by five groups that provide in-service inspection services to the commercial nuclear power industry. In addition to evaluation of the flaw detection and analysis capability of the techniques used by these inspection groups, the variables of code interpretation, procedures, techniques, standards, equipment, and training were studied.

The study evaluated code-approved ultrasonic inspection techniques. Since the complete in-service inspection process as shown in Figure 2 utilizes other inspection techniques to verify the results of ultrasonic inspection, a later phase of the study will evaluate the performance of in-service radiography as a complement to ultrasonics. Figure 2 also indicates the steps in the in-service inspection process evaluated and reported in this phase of the study.

The practical realism of the study was enhanced by using actual cracked bypass and core spray lines obtained from two BWRs. The flawed pipe sections were slightly radioactive and were examined under partial simulation of field conditions requiring radiation work procedures, special clothing, and some limitations in accessibility.

Figure 1 Ultrasonic signal from a stress corrosion crack can be seen on oscilloscope screen, together with several high-amplitude spurious signals.

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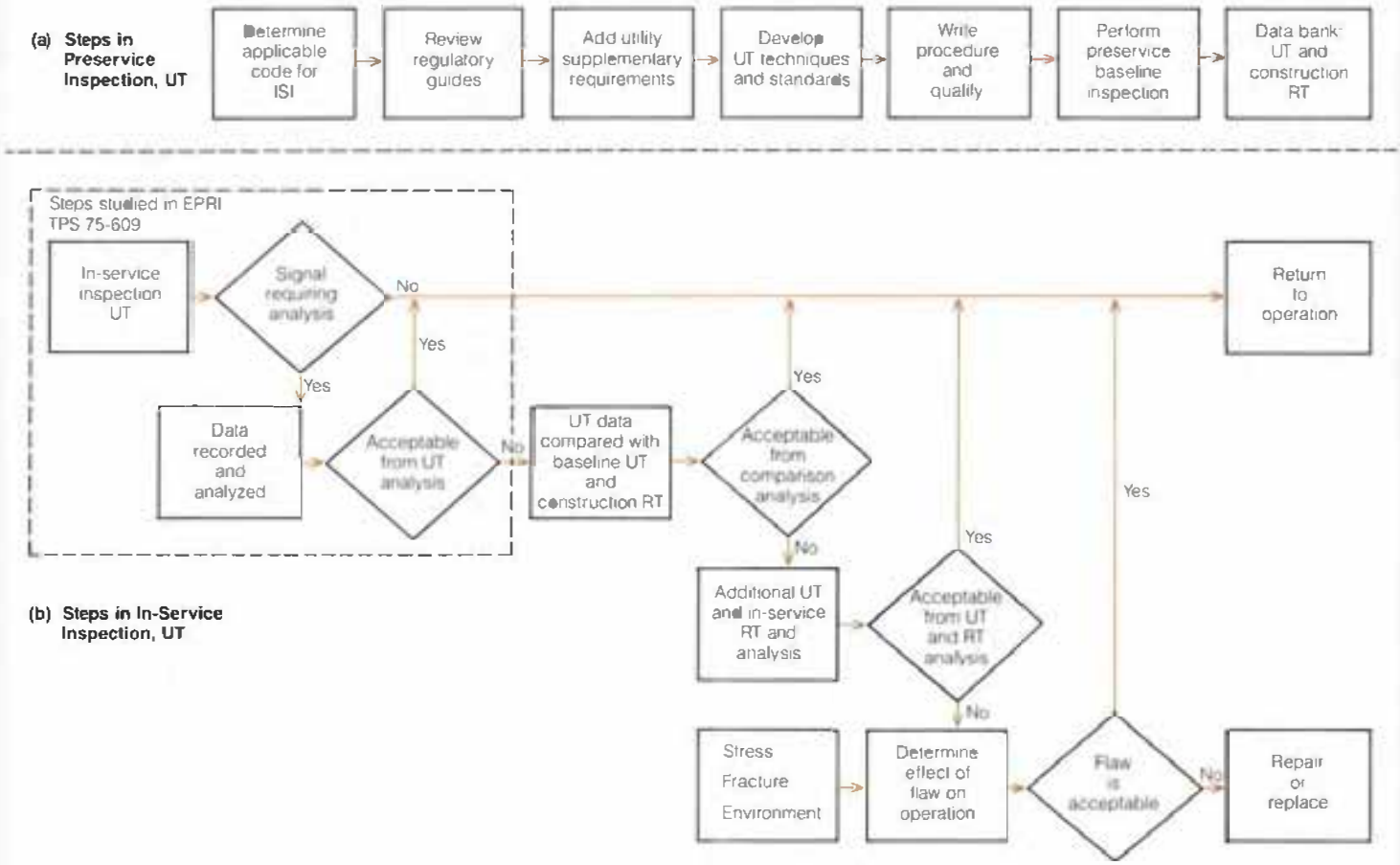
Figure 2 Logic diagram of the steps in the in-service inspection process, showing the relationship of the steps studied in EPRI TPS 75-609 to the rest of the process.



Planning the program

The EPRI study was designed to evaluate current practice for in-service ultrasonic inspection of BWR pipe welds. Its aim was to gain insight into the factors affecting in-service inspection performance within the range of code-approved practices. This evaluation also helped to determine flaw detection probabilities and to establish a baseline on which to build future work on improved techniques.

To achieve a true representation of industry practice, participants in the study were selected according to the following criteria.

- They must have had current experience in doing in-service inspection for the utility industry (as a major activity of each organization).
- They must have been currently involved in the inspection of stainless steel piping in BWRs, including the special in-service inspection required by NRC in late 1974 and early 1975 (*5, 6*).

Of eight inspection groups that satisfied these criteria, five were selected.

Since this study was aimed at evaluating representative industry inspection teams, certain qualifications were established for individual members of the three-member teams. Two members were to be Level II inspectors in ultrasonic examination, as defined by the latest edition of the American Society of Nondestructive Testing (ASNT) document SNT-TC-1A, *Personnel Qualification*. These inspectors must have participated in actual in-service inspection of BWR piping during the calendar years 1974 and 1975.

The third member was to be a Level III inspector in ultrasonic examination, who had participated in actual analysis of data obtained from the in-service inspection of BWR piping.

To evaluate the variables associated with in-service inspection, each group was requested to conduct a typical inspection using its normal procedures, techniques, standards, and equipment. These inspection procedures represented the existing ASME Section XI code requirements as of May 1, 1975; they were not to include any changes suggested by the 1975 Appendix III addition to the code (*7*).

All inspections were conducted in a radioactivity control area at the Vallecitos Nuclear Center of General Electric Co., Pleasanton, California. To simulate field conditions, the following procedures were adopted.

- BWR pipe samples containing actual stress corrosion defects were selected for inspection. Access was permitted only to the outside surface. The samples were either closed at both ends or mounted on wooden pallets. A number of unflawed samples were also inspected. The identity of flawed and

unflawed samples was concealed by a "double blind" procedure.

- Because the pipe samples, although decontaminated, retained some degree of residual radioactivity, inspectors were required to wear full anticontamination clothing (cloth overalls, cap, shoe covers, and gloves).
- To further simulate field conditions, a time limit was placed on the evaluation of each set of samples.

The test samples used in this program were sections of pipe containing circumferential welds. Most samples were 10-in. schedule 80, Type 304 stainless steel seamless piping (0.594-in nominal wall thickness). The majority of 10-in samples were cut from the core spray line of the primary system of an operational BWR (figures 3, 4, and 5). The other samples were 4-in. schedule 80, Type 304 stainless steel seamless piping (0.337-in nominal wall thickness). The majority of 4-in samples were cut from the bypass lines of the primary system of an operational BWR (Figure 6).

Before the study began, each sample was examined by pulse-echo ultrasonics, using longitudinal wave and shear wave (various angles) inspection techniques. The inside surface of each sample was also inspected using dye penetrant. The approximate depths of flaws were determined with an electric resistance gage. Wherever possible, supplemental volumetric NDE was performed with radiography (Ir_{192} and X ray). Limited metallurgical examinations were also carried out on material cut from a number of samples to confirm the presence of stress corrosion flaws. To aid in evaluating the accuracy of locations of flaws by each group, a reference mark was stamped on the centerline of each weld. The groups were instructed to make all measurements from this reference mark when plotting data on specially prepared forms.

After the groups completed the study, the samples were descaled, decontaminated, and reexamined by dye penetrant, ultrasonics, and radiography. Some samples were then sectioned and examined using metallographic techniques. The metallographic examination included determination of degree of cold working, sensitization of structure, intergranular cracking, grain size, hardness, and location in or out of the heat-affected zone. Photomicrographs, photomacrographs, and scanning electron microscope photographs were also taken of the crack surface. These examinations, performed at Battelle, Columbus Laboratories, are summarized in Table 1.

Figure 3 A typical 360° section test sample cut from a 10-in core spray line.

Figure 4 A typical 180° section test sample of 10-in core spray line.

Figure 5 Typical 36° section test samples of 10-in core spray piping.

Figure 6 Test samples cut from 4-in recirculation bypass lines.

Steps in the study

To evaluate the many aspects of in-service inspection, the study was divided into three phases. In Phase A each inspection group was asked to supply its own procedures, standards, and inspection equipment. The main objective of this phase was to determine present inspection practice and performance by representative industrial inspection groups. In Phase B all pipe samples were reinspected, but the groups used identical procedures, techniques, standards, and equipment as determined and supplied by EPRI. The objective of this phase was to determine inspection team performance on a common ground, with the variables of different procedures, equipment, and standards eliminated. Phase C examined the variability in response from various field calibration standards.

Each test group took two weeks to complete all phases of the study. Throughout the simulated inspections, a test monitor remained at the site to coordinate the inspections, collect data and field reports, and observe the performance of the various groups.

Each test group was given a specified number of samples and allowed a definite time period in which to evaluate them. The samples were then removed and replaced by a new set. Between phases A and B, the samples were disguised and given new identifications and the composition of each set was changed. The groups were not told that they were, in fact, conducting two evaluations of the same set of test samples. Although some recognition of the samples

Table 1

TEST SAMPLE LISTING AND TESTS PERFORMED

Sample Identification	Pipe Diameter (in)	Pipe Segment (degrees)	Preliminary Flaw Description	Pipe Cross-Section Quadrants				Battelle-Columbus Examinations						Final Evaluation
				1	2	3	4	VI	DPT	RT	ERG	UT	Met	
19AL	10	180	SCC, radial, through wall	*			†	X	X	X	X	—	—	Cracked (through wall)
1028A	10	36	SCC, circular, across sample	*				X	X	X	X	—	—	Cracked (0.5 in)
1021	10	360	SCC, circular, 8 in long	†	*	*	†	X	X	X	—	—	X	Pipe material defect (lap ~0.025 in)
10K17L	10	360	SCC, circular, small spots	†	*	*	†	X	X	X	X	X	X	Single porosity
1028B	10	36	SCC, at angle; edge crack	*				—	—	—	—	—	—	Cracked‡
1024A	10	180	SCC, circular, radial and angular, spotty	*			*	X	X	X	X	X	X	Cracked (0.5 in max)
10K18	10	360	Lack of fusion; possible SCC	*	*	*	†	X	X	X	X	X	X	Lack of fusion
10K17	10	360	None	†	†	†	†	X	X	X	X	—	—	Acceptable weld
1020A	10	360	None	†	†	†	†	X	X	X	—	—	X	Overlap of weld root
1024B	10	180	None	†			†	—	—	—	—	—	—	Acceptable weld‡
1028C	10	36	None	†				X	X	X	—	—	—	Acceptable weld
1028D	10	36		†				—	—	—	—	—	—	Acceptable weld‡
1019A	10	360	None	†	†	†	†	X	X	X	—	—	—	Acceptable weld
19BL	10	180	None	†			†	X	X	X	—	X	X	Acceptable weld
B2A	4	360	SCC, small spots	†	*	†	†	—	—	—	—	—	—	Cracked‡
A9A	4	360	None	†	†	†	†	—	—	—	—	—	—	Acceptable weld‡

* Quadrant identified as flawed by General Electric.
† Quadrant identified as good weld by General Electric.
VI Visual inspection.
DPT Dye penetrant testing
RT Radiographic testing
ERG Electric resistance gauging
UT Ultrasonic testing
Met Metallography
X Tests performed
— Test not performed
‡ Evaluation by General Electric only; not examined by Battelle-Columbus

undoubtedly occurred during the second phase of the study, the subtle differences in data and results obtained by the groups indicate that each sample was actually evaluated by different procedures. The observations of the test monitor confirmed this opinion.

At the end of each inspection day, all data were collected by the test monitor; at the end of each phase, all data were transferred to a summary data sheet. Between phases, a brief discussion of the results was conducted with each group. Besides providing a preliminary evaluation of each group's performance, these debriefings gave valuable insights into the inspection philosophy presently used in the nuclear industry.

Summary of the round-robin tests

The laboratory and destructive examinations (Table 1) provided a basis for evaluating the flaw detection and analysis capability of the test groups.

In the five pipes containing stress corrosion cracks (19AL, 1028A, 1028B, 1024A, and B2A), the majority of inspection groups found indications of stress corrosion cracks, identified the pipes as cracked, and located the cracks accurately. The five test groups performed two inspections for each of the five cracked test specimens, for a total of 50 separate inspections. In 43 of these inspections, the groups successfully detected flaws. Successful detection is defined as an indication plotted in the proper location on the pipe with accompanying ultrasonic amplitude data. Of the 43 detections, 28 were successfully analyzed as service-induced cracks. Successful analysis is defined as calling a plotted indication a crack. Terms such as *linear indication* or *defect indication* were not acceptable in this analysis. In field practice, such indications would call for additional confirmatory inspections, but they are obviously less useful to the utility than a clear call.

For the two specimens containing lack-of-fusion or lap flaws, 18 separate inspections were performed by the five groups (one group did not inspect one of the specimens). In all 18 inspections, the flaws appeared to have been detected successfully, although in most cases the differentiation between stress corrosion crack and lack of fusion was not made. In some cases, a group's original data were reviewed to determine whether the flaw had been detected but not reported on the EPRI data form. In fact, some groups did apparently detect marginal indications in these two specimens but interpreted them as not significant enough to report. Of the 18 inspections, 10 were successfully analyzed as lack of fusion or

a crack (either definition was accepted)

For the nine nondefective pipe samples, two inspections of each were performed by the five groups for a total of 90 inspections. Twenty-three of these inspections resulted in calling a sample cracked. One pipe sample containing an internal fabrication reflector contributed to seven of the inspection overcalls. Another sample containing sharp changes in section on the inside surface contributed to four of the miscalls. The remainder of the miscalls were randomly distributed; they may be attributed to weld fabrication anomalies. As the inspection groups pointed out, many of these miscalls might have been eliminated by fabrication inspection data or by supplemental inspection techniques, such as radiography. Although there were several miscalls of unflawed pipe as flawed, the correct analysis of cracked pipe tends to outweigh significantly the calling of uncracked pipe as defective. The tendency to overcall indicates a conservative inspection philosophy that could result in excessive time for added inspections or unnecessary repair of unflawed pipe during a reactor outage. However, this conservative approach would allow fewer flaws with a potential for growing to a leak condition to remain in the piping system. The repair of a leaking flaw that causes a forced outage is an order of magnitude more costly in plant availability than the same repair during a normal period of reactor shutdown.

Since some of the specimens contained several flaws with various depths and orientations, the individual flaws were analyzed to determine what effect flaw size, shape, and orientation had on defect detection and analysis. The most significant finding was that the orientation of a flaw appears to be a more significant controlling factor than depth. Flaw shape (high depth-to-surface-length ratio) also contributes to lack of detection. Skewed cracks (those not parallel or perpendicular to the weld) were extremely difficult to detect in the simulated inspections using the normal field inspection procedures of scanning parallel and perpendicular to the weld. These cracks were detected in the laboratory by rotating the transducer. Earlier observations of field-cracked pipe indicate that only rarely do skewed cracks occur in which no portion of the crack surface has an orientation parallel or perpendicular to the weld centerline.

The overall results and relative performance of the groups suggest that a conventional transducer diameter greater than 0.375 in (with conventional wedge) may reduce reliability in detecting stress corrosion cracks in some 10-in pipe because of physical interference between the front edge of the search unit and the raised weld crown. This observation was later verified by a laboratory study.

Variables influencing reliable inspections

The principal difference between these inspections and inspections for other types of flaws was the way in which the data were analyzed. The procedure that was most successful both in correctly identifying flaws and in avoiding miscalls or overcalls involved careful plotting of UT data on cross-section drawings of the weld configuration. The location of the source of a suspect signal was used to help decide its identity (e.g., geometry, stress corrosion crack, lack of fusion). An effective criterion was that stress corrosion cracks usually occur in the heat-affected zone between the fusion zone of the weld and the inside diameter counterbore.

The overall results of this program indicate that pulse-echo shear wave ultrasonics is a viable in-service volumetric inspection method for the detection of intergranular stress corrosion defects in welded 300 series stainless steel core spray lines of BWR reactors. (There were not enough samples of bypass lines in the program to draw conclusions.) If the mechanism of intergranular stress corrosion cracking has started in the primary system of a BWR, and if the historical pattern of crack growth is present (cracks at various depths and orientations and in more than one location), there is a high probability that the presence of this mechanism will be detected by a well-trained inspection crew using present in-service inspection methods. (Under actual field conditions, limitations of physical access may sometimes be important.) The detection and analysis of *small* intergranular stress corrosion flaws at one or more locations in the total piping system could be missed or incorrectly analyzed. This possibility is higher than desirable, and early detection while cracks are still sparse could pay off in avoiding more outages. The technique is not sensitivity-limited, since very small flaws can be detected; however, the fundamental problem in using the technique is to correctly recognize the detected signals as signals from a flaw rather than from other sources.

The final results of the inspection process still appear to depend to a considerable degree on the decision-making process of the individual inspector, and any improvement in this area would have the greatest near-term effect on the total inspection process. To make flaw detection more completely objective and independent of operator skill and experience is a highly desirable goal for any equipment or technique.

Equipment, techniques, codes, and procedures influence the inspection process to a lesser degree, but considerable short-term improvement in one or all of these areas appears possible, as past development effort for inspecting intergranular stress corrosion cracks appears minimal. Access, working conditions, and limited inspection time also influence the inspection process, but their contribution is difficult to assess and to correct on a short-term basis.

The most important drawback in using the ultrasonic technique is the time-consuming analysis required to distinguish flaws from other signals and the consequent tendency to miscall fabrication anomalies as service-induced cracks. Other limiting factors include the rather low signal-to-noise ratio where geometric irregularities occur and the considerable difficulty in detecting small cracks that are skewed relative to the principal axis of the pipe. Data from previous inspections and supplemental inspection techniques such as radiography can assist in the analysis and decision-making process, and these aids are commonly used. Their exact contribution to improvement of the inspection process was not studied in this phase of the program.

As the results of this study (*8*) suggest several practical directions for seeking improved inspection analysis capability, further effort is under way to develop and apply such refinements (RP892).

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5. "Through-Wall Cracks in Core Spray Piping of Dresden 2," AEC Office of Inspection and Enforcement Bulletin, IE-75-01, January 30, 1975.

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8. *A Study of In-Service Ultrasonic Inspection Practice for BWR Piping Welds*. Summary Report for TPS 75-609, prepared by E. R. Reinhart, June 1977. EPRI NP-436.

New Technical Reports

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, Printing and Graphics, P.O. Box 10412, Palo Alto, California 94303. Reports are publicly available from the National Technical Information Service, P.O. Box 1553, Springfield, Virginia 22151; and from Research Reports Center, P.O. Box 10090, Palo Alto, California 94303.

ELECTRICAL SYSTEMS

Symposium proceedings: new concepts in fault current limiters and power circuit breakers

EL-276-SR Special Report

Serious industry attention is being directed toward developing fault current limiters and improving power circuit breaker interrupters through R&D programs at EPRI, ERDA, and other research organizations. A symposium, held on September 28, 29, and 30, 1976, at the State University of New York at Buffalo reviewed findings provided by these programs.

The symposium was equally divided between presentation of papers and open discussions among the participating researchers, designers, application engineers, and utility operations personnel. The subject of power circuit breakers was covered from the fundamental aspects of arc physics to design and development of gas, vacuum, and combination interrupters. Both switched-resistor and tuned fault current limiters were presented. Considerable general discussion centered around potential application and need for fault current limiters. Two electric utility papers were presented on the subject of application.

Gas-insulated, fluidized-bed transformer

EL-302 Final Report (RP477-1)

A study of corona and breakdown voltages for glass beads or for TFE particulates fluidized by SF_6 evaluated effects of gap distance, pressure, field uniformity, fluidizing gas velocity, and electrode orientation. The data were compared with those for pure SF_6 without particulates under the same conditions. A correlation of Reynolds number versus Nusselt number for fluidized beds facilitated an estimate of the heat transfer coefficient of glass beads and of TFE particulates. The study included a computation of the fluidizing of the experimental system.

It was concluded that, due to decreased electrical properties, use of fluidizing glass beads would be unsatisfactory in transformers. TFE particulates showed promise and are worthy of further evaluation. *Allied Chemical Corp.*

A program to evaluate, develop, and test Poroplastic materials as improved electrical insulation for high-power underground cables

EL-312 Final Report (RP7842-1)

This report presents the results of a project to develop Poroplastic film, an ultramicroporous material invented by Moleculon Research Corp. as a low-loss substitute for the cellulose paper tapes presently used in the manufacture of high-pressure oil-filled cable. Structurally, Poroplastic is a stable film consisting of a cellulose triacetate matrix, which incorporates a large volume of liquid. Pore diameters in the matrix measure several tens of angstroms and the relative liquid volume can be controlled to range from as little as 50% to as much as 95%. The film's dimensional stability depends on the presence of the liquid within the matrix; loss of liquid through evaporation or high-pressure expulsion leads to irreversible matrix collapse. *Moleculon Research Corp.*

A study of underground power cable installation methods

EL-374 Final Report (RP7824)

The cost of installing underground high-voltage transmission cable can be 50% of the total circuit in-service cost. This study was directed toward underground cable systems in service and those types that can be commercially available in the near future. The report presents a detailed examination and range of costs of various installation steps. Research and development are recommended in three general areas of installation procedure: route planning and design, pavement and soil removal, and pipe installation methods. Recommenations in route planning and design area include improved computer routing, subsurface preliminary surveying, and thermal analysis of in situ soils, backfill material, and geometric arrangement of cable circuits in the trench. In pavement and soil removal, improved methods are recommended for microwave, plasma torch, and water jet concrete cutting; guided boring systems; shoring techniques; and soil removal systems. Installation of pipes yielded recommendations for automatic welding techniques, integrated transmission systems, and standardization of accessories and equipment among utilities. *Arthur D. Little, Inc.*

Superconducting cable system

EL-402 Final Report (RP7807-2)

This report outlines the technical and economic problems pursued in a 46-month EPRI–ERDA program to develop an ac superconducting power transmission line. Unforeseen difficulties were encountered with power losses in the superconductor, eddy current losses, and heat leak. Fault current testing was never attempted. Major dielectric problems prevented operation of the system at 138 kV.

Ac loss data on small samples of electroplated niobium and a preliminary cost estimate indicate that this type of cable system might be attractive for moving large blocks of power if it could be developed to meet utility needs. The report presents a conceptual design for the rigid conductor, rigid cryogenic enclosure, helium-spacer insulated superconducting cable system based on R&D to date. *Union Carbide Corp.*

Development of extruded dielectric underground transmission cables rated 138 kV, 230 kV, and 345 kV

EI-428 Final Report (RP7829-1)

The objective of this project was the development of 138-, 230-, and 345-kV cross-linked polyethylene (XLPE) insulated cables with insulation thicknesses corresponding to those of high-pressure oil-filled pipe-type cables and with reliability acceptable for high-voltage transmission systems. *General Cable Corp.*

ENERGY ANALYSIS AND ENVIRONMENT

Fuel and energy price forecasts

EA-411 Final Report (RP759-2)

EPRI and the electric utility industry require fuel price forecasts for use in planning. The Energy Analysis and Environment (EAE) Division has a contract research program under way to develop information on which to base such forecasts.

This is a long-range program involving much fundamental energy economic and analytic work. Full results will not be available for some time. In the meantime, energy price forecasts required for R&D planning and other purposes have been undertaken by Stanford Research Institute (SRI) (RP795-1) and Foster Associates, Inc. (RP759-2) to prepare independent price forecasts to the year 2000. The SRI data have been published as *Fuel and Energy Price Forecasts, Volume II* (EPRI EA-433). Volume I, the actual forecasts, will appear soon.

While the Foster Associates study was designed primarily to aid the EAE staff, it is being published, in accordance with EPRI policy, so that it may be used by electric utility staffs and others. It should be emphasized that the forecasts contained in this report are the contractor's, and the publishing of them does not imply their endorsement by EPRI. The contractor and Project Manager did not agree on all the logic, data, and assumptions, and the reader is cautioned to fully examine the basis of the forecasts before using them. The report should be useful to those attempting a better understanding of future energy prices and the complexities surrounding them. Because of the contractor's background and funding limitations, more attention is given to the natural gas deregulation case than to the crude oil deregulation case. This in no way reflects a belief on the part of the Supply Program that crude oil deregulation is not at least an equally important subject or that there would not be a significant supply response from such deregulation. It does not imply any judgment as to the desirability of deregulation from the national viewpoint in either case but is rather a judgment as to supply response. *Foster Associates, Inc.*

Stanford–EPRI workshop for considering a forum for the analysis of energy options through the use of models

EA-414-SR Special Report (RP875-1)

Models have something valuable to offer decision makers in helping to define problems and clarify the complex environment of interconnected relationships. The greatest benefit of models is in forming, refining, and testing mental conceptions of the problem terrain.

This benefit has been illustrated in the public sector more by the value of models to modelers

than to decision makers. Any honest modeler will admit that it is more fun building a model than interpreting or documenting it. Decision makers lack a firm basis for selecting models and understanding their potential contributions. A modeling activity underdeveloped at the present time, third party model analysis, needs to be established, promoted, and supported. The Energy Modeling Forum is one attempt to meet this need and provide the analysis and communication of energy modeling capabilities. This report summarizes the July 1976 workshop discussion on the design and operation of future Forum activities. *Stanford University*

Time-variable air pollutant emission strategies for individual power plants

EA-418 Final Report (RP487-1)

This study evaluates the feasibility, operational characteristics, and potential cost savings of time-variable emissions control systems for a site in the northern Great Plains region. Two years of data are applied to models for defining and evaluating time histories of pollutant emissions, which satisfy all relevant air quality standards and minimize the operational costs of emissions control. These strategies were examined under several scenarios, which varied the number of emissions modes, stack height, emissions control cost assumptions, maximum pollutant generation rate, and local dispersion rate.

On completion of this study, EPRI sponsored a workshop on supplementary environmental control systems (SECS, or time-variable air pollution emission strategies) to determine directions of future EPRI research on the subject. Conclusions and recommendations of the workshop are available in EPRI EA-279-SR (WS76-70). *The Research Corporation of New England*

Guidelines for estimating present and forecasting future population distributions surrounding power reactor sites

EA-427-SR Special Report

As a part of the licensing procedure for building a nuclear power plant, the Nuclear Regulatory Commission requires applicants to provide estimates of the total population and the population distribution within a 50-mile radius of the proposed site at the time of application and throughout the lifetime of the power plant. This information must be included in the environment report and in the safety analysis report. The methods for estimating and projecting the required information fall within the discipline of demography, but there are no guidelines that define methods suitable for generating the needed data.

This report presents the output of a workshop convened to draft guidelines for estimating and forecasting population distributions around power plants. The workshop was motivated by the efforts of the American Nuclear Society to draft a proposed American national standard for estimating present and forecasting future population distributions surrounding proposed power reactor sites. The draft standard presented in the report is only the first draft. Many additional persons will be given the opportunity to review it before an American national standard is approved. *Sigma Research, Inc.*

Fuel and energy price forecasts

EA-433 Final Report (RP759-1)

EPRI and the electric utility industry require fuel and energy supply (price-quantity relationship) forecasts for use in planning. The Supply Program has a contract research program under way to design and develop improved fuel and energy supply forecasts. This is a long-range program involving much fundamental energy economic and analytic work, and full results will not be available for some time. In the meantime, forecasts have been undertaken by Stanford Research Institute (SRI) and Foster Associates, Inc. (RP759-2). The results of the Foster Associates work have been published as *Fuel and Energy Price Forecasts, Volumes I and II* (EPRI EA-411).

SRI's forecasting effort is based primarily on its national energy model, originally developed for Gulf Oil Corp. This complex model requires a large amount of input. This second volume of SRI's fuel and energy price forecast describes the inputs to the model and provides a summary description of the model as of August 1976. Volume II is being published a couple of months before publication of Volume I, which will contain the actual forecasts. Much of the data used in earlier applications of SRI's national energy model have been updated and improved. It must be emphasized that all the data and information contained in this report were developed by SRI; EPRI's publication of this information does not imply endorsement of it by EPRI. *Stanford Research Institute*

Evaluation of CHESS: New York asthma data 1970–71, Vol. I. Findings and supporting tables

EA-450 Final Report (RP681-1)

This report is one of a series evaluating state of knowledge and research needs regarding health effects of air pollution. A report on sulfur oxides (EPRI EA-316) has already been published; forthcoming documents will cover nitrogen oxides, particulates, and oxidants. This publication is the first of a group consisting of detailed reanalysis and interpretation of epidemiological data and dealing specifically with the studies for the Community Health and Environmental Surveillance System (CHESS).

Between 1967 and 1975, the Environmental Protection Agency carried out a comprehensive research program on possible relationships between air pollution and concurrent morbidity. Air pollution data included measurements of SO_2, particulates, total sulfates, CO, ozone, hydrocarbons, NO_2, and nitrates. Concurrent epidemiological studies included observations on acute and chronic cardiac and respiratory illness, ventilatory function of children, and aggravation of asthma symptoms. The CHESS report has been the subject of considerable controversy, leading to an intensive evaluation by a congressional subcommittee.

This report presents a careful statistical reanalysis of one data set from CHESS epidemiological studies in greater New York in 1970–71. The original analysis of this data set linked increased asthma attack rates with suspended particulate and suspended sulfate air pollution. The reevaluation of the data reported here does not support the hypothesis of a positive association between asthma attacks and levels of suspended particulate or ambient sulfate levels, as suggested by CHESS researchers. *Greenfield, Attaway & Tyler, Inc.*

FOSSIL FUEL AND ADVANCED SYSTEMS

UWMAK-III, a noncircular tokamak power reactor design, Vol. I

ER-368 Final Report (RP237-2)

UWMAK-III is a conceptual power reactor design study aimed at understanding the problems associated with advanced technologies and several new or different design approaches in tokamak systems. Advanced technologies studied include the use of the molybdenum-based alloy TZM as the primary structural material, the use of aluminum as the stabilizer and aluminum alloy structure for the NbTi superconducting magnets, and the use of a closed-cycle helium gas turbine power conversion system.

New or different design approaches include RF (fast magnetosonic waves) plasma heating, a blanket design where tritium breeding is accomplished only in the outer blanket region, a permanent inner blanket that is basically a hot shield, tritium extraction and recycling processes, and the general design approach to blanket module removal. The maximum module weight is only 42 t. An MHD analysis has determined the noncircular plasma shaped as a characteristic "D" with neutral points on the plasma boundary for a poloidal divertor. The reactor is small (major radius = 8.1 m) with a relatively high β (about 9%), and an average neutron wall loading of 2.5 MW/m². It is designed to generate 5000 MW(th) during the burn and 1985 MW(e) continuously. The net plant efficiency is about 42%.

Aspects of the design study include the reactor plasma physics of a noncircular reactor plasma, theory of divertor operation, vacuum system design, toroidal and poloidal field superconducting magnet analysis, blanket design and neutronics, thermal hydraulics and mechanical design, tritium handling, extraction, and recycle, neutron-induced radioactivity, materials properties and radiation damage, helium gas turbine power cycle design, balance of plant considerations, resource implications of the design, and an economic analysis. *University of Wisconsin*

Utilization of U.S. geothermal resources

ER-382 Final Report (TPS76-638)

Geothermal resources expected to be economic for near-term U.S. electrical use are almost all in moderate to high-temperature hydrothermal systems located in the western states. Known hydrothermal systems lie in geographically narrow, continuous tectonic belts marked by faults, volcanism, and earthquakes. Most undiscovered hydrothermal resources can be expected to lie in the same belts, which pass through the service areas of a number of major and many smaller western utilities.

This study is concerned with U.S. geothermal resources, their potential for commercial utilization by electric utilities between now and the year 2000, and their impact on the utility industry. U.S. Geological Survey estimates of the resources in identified hydrothermal systems are extrapolated to the undiscovered resources marked by hot springs, and further to the blind resources between hot spring areas within the tectonic belts. Water rates and direct capital costs for geothermal power plants are evaluated as functions of resource temperature, together with costs and expected flow rates for geothermal wells. A supply curve for geo-

thermal energy combines these results with the temperature distribution of identified hydrothermal systems. *TRW Inc.*

Assessment of titanium for use in the first-wall/blanket structure of fusion power reactors
ER-386 Topical Report (RP472-1)

This report describes a portion of the work that was performed as part of a first-wall/blanket systems analysis study. The objective of this part of the study was to assess the suitability of using titanium alloys in the first-wall/blanket structure of commercial controlled thermonuclear reactors (CTRs). Two near-alpha titanium alloys were selected for in-depth examination, Ti-6%Al-4%V (called Ti-6Al-4V) and Ti-6%Al-2%Sn-4%Zr-2%Mo (called Ti-6242). Both materials are commercially available in standard mill forms with weldable forgings, and they have a large data base. The Ti-6Al-4V alloy was developed in 1954 and is fairly representative of an all-purpose alloy. The Ti-6242 alloy was specifically designed to meet the high-temperature requirements of the aerospace industry. It is noted for its creep resistance and metallurgical stability up to temperatures of 550°C. Using properties important to the CTR first-wall/blanket structures application, these alloys were compared with five other candidate structural materials (2219 aluminum, 316 stainless steel, V-20 Ti, Nb-1Zr, and Mo-0.5 Ti-0.08 Zr [TZM]). The study revealed that titanium offers potential for use in a CTR from the standpoints of strength, minimum radioactivity, and resources. *McDonnell Douglas Astronautics Co.*

Comparative evaluation of high- and low-temperature gas cleaning for coat gasification–combined cycle power systems
AF-416 Final Report (RP243-2)

The purpose of this screening study was to evaluate incentives for developing hot gas purification technology for coal gasification–combined cycle power generating systems. The iron oxide process currently being developed by the Morgantown Energy Research Center for removal of hydrogen sulfide at high temperature (1000°F) was selected for investigation as it was judged to be in a more advanced stage of development than other current high-temperature absorption processes.

This report presents process and economic evaluations for five different coal gasification schemes: air and oxygen blown dry ash; moving bed Lurgi gasifiers; oxygen blown stagging; moving bed gasification (currently being developed by the British Gas Corporation); and oxygen and air blown two-stage entrained gasifiers (proposed by Foster Wheeler Energy Corp.). Results include, for each scheme, four complete system flowsheets for converting Illinois No. 6 coal to electricity via combined cycle power generation. Two of these schemes were based on high-temperature iron oxide technology with gas turbine inlet temperatures of 1950°F and 2400°F. The other two flowsheets incorporated the low-temperature Benfield process with gas turbine inlet temperatures of 1950°F and 2400°F. *Stone & Webster Engineering Corp.*

Coal liquefaction by alkylation
AF-423 Final Report (RP258)

A study of the Friedel-Crafts alkylation of coal was undertaken to determine whether the introduction of alkyl groups would result in the production of a pumpable liquid fuel from coal, as predicted by one popular coal structure model. Successful alkylation could offer a low-severity, nonhydrogenation route to coal liquefaction. Several coals alkylated with isobutylene in sulfuric acid were studied for solubility, melting behavior, and NMR spectra. Production of a readily pumpable liquid was not achieved. Several techniques were developed for studying the interactions of coal surfaces with a variety of materials. *University of Tennessee*

Preliminary investigation of the autoadhesion of pulverized SRC
AF-431 Final Report (RP779-8)

This report presents the results of a preliminary investigation of the surface properties of solvent-refined coal (SRC) and how they contribute to autoadhesion. Reactive surface sites on SRC were characterized by volumetric adsorption and by temperature-programmed desorption of H_2, O_2, CO_2, HCl, NH_3, H_2O, and diethylamine. The adsorbing surface sites of SRC are reactive mainly because they are acidic or basic. These were made to determine whether some of the adsorbed molecules altered compaction during pulverization of SRC or altered autoadhesion of pulverized SRC. Angle of repose measurements were used to indicate autoadhesion of pulverized SRC. Water, but not the other gases, affected the results. Other experiments showed that the surface oil and static charge on SRC do not contribute to autoadhesion. *Stanford Research Institute*

Comparison of phased cooling systems with conventional cooling systems: performance and economics
FP-432 Final Report (RP321)

This report introduces and analyzes two new concepts in heat dissipation: phased cooling, the operation of a cooling system in various modes (phases) during a 24-hour period in order to take maximum advantage of environmental conditions; and the rejection of heat by an "interstellar radiator" instead of a cooling tower or pond. The two concepts are combined in a phased-radiator heat rejection system whose performance and economics are compared with natural draft wet towers and cooling ponds in Birmingham, Philadelphia, Portland, and Phoenix. The phasing concept is also applied to a dry tower (a phased-dry tower), and its performance is compared to a conventional dry tower. *Auburn University*

Workshop on synthetic fuels from fusion
ER-439-SR Special Report

A two-day workshop, held on February 9 and 10, 1976, brought together plasma physicists, fusion reactor designers, radiation chemists, and fuel scientists to discuss potential uses of thermonuclear fusion reactors in the production of synthetic fuels. Three working groups explored specific mechanisms by which the various outputs of fusion reactors, including thermal, electrical, neutrons, gamma radiation, charged particles, and electromagnetic radiation, might be effectively utilized.

The general conclusion of the groups was to vigorously pursue a program to define and explore the nonelectrical outputs of fusion reactors in order to help meet fuel shortages and to aid in the early availability of fusion reactors by simplifying some technical restraints. It could also aid in the longer term by greatly increasing the overall efficiency (into both electrical and nonelectrical outputs) of fusion power plants as compared with competitive energy sources. *Ben Eastlund Fusion Systems Co.*

NUCLEAR POWER

Analysis of N-16 radiation measurements at the Cooper Nuclear Station
NP-243 Final Report (TSA75-27)

This report describes the evaluation of radiation measurements (N-16 gamma-ray dose rates) at various locations on the surface turbine equipment components on the roof and in the vicinity of the Cooper Nuclear Station. Calculations of source strengths were based on an assumed N-16 activity of 113 μCi/gm of steam at the reactor nozzle. This evaluation aids in assessing the usefulness of available analytic techniques to predict radiation levels around BWRs due to N-16 gamma rays originating in the turbine room of these plants. It also helps demonstrate BWR ability to meet site boundary dose rate limitations required by government regulatory agencies.

Included in the report are descriptions of the QADMOD point kernel radiation transport code and the SKYSHINE procedure. These computer codes were used to compute the N-16 source strengths in the turbine equipment and the N-16 dose rates at the various detector locations. Also described are the computer models used to represent the turbine equipment sources and the structure of the turbine building in the computer calculations. *Radiation Research Associates, Inc.*

Oconee Nuclear Station, unit one, cycle two, refueling shutdown: primary system radiation levels
NP-340 Final Report (TPS76-634)

This report features the results of an extensive survey of the radiation fields at three stations using Babcock & Wilcox nuclear steam supply systems: Oconee 1 and Oconee 2 operated by Duke Power Co. and Three Mile Island 1 operated by Metropolitan Edison Co. Radiation fields at Oconee 1 measured at the second refueling shutdown were comparable to other PWRs of similar age. But fields at Oconee 2 and Three Mile Island 1 at first refueling shutdown were lower than at plants of comparable ages. The report also lists significant radioisotopes present in aqueous samples taken from the fuel transfer canals and the reactor coolant systems as well as corrosion products identified as the principal source of radiation fields for the primary coolant system.

The development of RELAP/SLIP for the semiscale blowdown heat transfer test S-02-6 (NRC Standard Problem 6)
NP-343 Interim Report (RP695-1)

This report and a companion report, NP-300, document work performed to provide a realistic prediction of NRC Standard Problem 6 (Test S-02-6). The RELAP/SLIP code is a modified version of RELAP4-95 and includes a first-level effort, state-of-the-art, dynamic slip calculation in all vertical and horizontal junctions to account for unequal phase velocity and phase separation. The dynamic slip model accounts for transient inertial effects of each phase. This report contains

the derivation of the dynamic slip field equations, a description of the modifications to the RELAP4 numerical scheme and recommendations for improved code performance. Several analytic problems and some experiment simulations, including NRC Standard Problems 1 and 5, were analyzed in an effort to check out the RELAP/SLIP code. Calculations compared favorably with homogeneous equilibrium experimental data and previous RELAP4-95 predictions. To the best of the authors' knowledge, the consistent, complete, and realistic computation of unequal phase velocities has been achieved for the first time in any general systems code with the successful simulation of the simple problems and Standard Problem 5 using RELAP/SLIP. *Energy Incorporated*

Experimental and statistical requirements for developing a well-defined K_{IR} Curve

NP-372 Final Report (RP696-1)

This report documents program development of a statistically well-defined reference fracture toughness curve as a potential replacement for the K_{IR} curve presently specified in Appendix G, Section III, of the ASME Boiler and Pressure Vessel Code. An alternative temperature indexing procedure for reduction of data scatter is also presented.

Existing EPRI test and data analysis procedures and acceptance criteria were revised to include the current requirements for elastic-plastic fracture toughness measurements. *Fracture Control Corp.*

Power reactor pressure vessel benchmarks: an overview

NP-380-SR Special Report

The continued assurance of the safety and integrity of nuclear reactor components requires an understanding of the changes in material properties that such components sustain as a function of irradiation and the radiation flux and spectrum to which they are exposed over the lifetime of the system. This report reviews the current status of experiment and calculation benchmarks for understanding radiation embrittlement effects in pressure vessels of operating LWRs. Included are requirements of such benchmarks for application to pressure vessel dosimetry, recent developments in active and passive neutron detectors sensitive in the ranges of importance to embrittlement studies, and recommendations for benchmark improvements.

Computation of crack propagation and arrest by simulating microfracturing at the crack tip

NP-412 Final Report (RP499)

Prevention of crack initiation is the first design defense against nuclear reactor pressure vessel structural failure. The ASME Boiler and Pressure Vessel Code delineates conservative design procedures to prevent crack initiation. However, to further assure the continued safety and integrity of nuclear reactor pressure vessels, we must develop the analytic ability to assure that in the unlikely event of actual crack initiation, the crack will arrest rather than propagate. The traditional method of assessing propagation-arrest has been through the use of the fracture mechanics parameter, K_{Ia}, crack arrest toughness.

This report presents the results of a study to evaluate an alternative method of describing crack propagation and arrest. This new methodology models the nucleation, growth, and coalescence of microfractures ahead of a running crack and how these parameters affect arrest. It provides a link between micromechanical material behavior and the traditional fracture mechanics approach to propagation and arrest. *Stanford Research Institute*

Probabilistic safety analysis

NP-424 Final Report (RP217-2-7)

This annual report summarizes work carried out during the second year of an LWR probabilistic safety analysis. (Progress in the first year was summarized earlier in an EPRI Interim Report, 217-2-4, *Probabilistic Safety Analysis*.) Each section of this report summarizes work in a particular area.

Section 2 describes the summary and critique of the complete Reactor Safety Study Report. Section 3 presents a summary of a detailed sensitivity perturbation analysis on two reactors. The second part of Section 3 contains the results of a detailed analysis of the most influential PWR sequence (relative to consequences), including a comparison of various design options suggested by NRC in the Standard Review Plan.

Part of the methodology examination included investigation of the WASH-1400 computer codes. Section 4 presents a family of codes developed to evaluate plant risk both quantitatively and qualitatively. For purposes of comparing different plants, a set of event trees, described in Section 5, was developed for a large PWR different from any examined previously. Three documents evaluating risks due to anticipated transients without scram and a summary of the areas of this problem yet to be studied are reported in Section 6. Section 7 summarizes an ongoing effort to gather actual plant failure data. And finally, Section 9 presents work to date on safety analysis verifiability, including a literature search and suggested studies. *Science Applications, Inc.*

An analysis of post-LOCA gamma-ray effects in representative LWRS

NP-425 Volume I: Final Report (RP492-1)

Nuclear Regulatory Commission regulations state that in the case of such an unlikely event as a loss-of-coolant accident (LOCA), certain important safety margins must be demonstrated, including the peak cladding temperature of the fuel and the amount of H_2 produced due to radiolysis in the coolant. The peak cladding problem is of concern in the short time frame (10^3 seconds) following reactor shutdown in a LOCA analysis, while for H_2 radiolysis, the time frame of interest is days and weeks.

This report describes the Monte Carlo technique and analysis used to determine gamma-ray deposition in two operating reactors of recent design. The first is a General Electric BWR at Nine Mile Point; the other is a Babcock & Wilcox unit at Oconee. The report attempts to derive redistribution factors for gamma energy around hot assemblies and to calculate the amount of gamma energy deposited in the coolant at various times after the start of a hypothetical LOCA. Volume I gives the details of the analysis and presents the results. Volume II (available only on request) provides the details of the ORIGEN calculations to produce the source strength at a time after shutdown and gives the actual power distribution at various times in the operating cycle.

A final report will soon be available on the experimental measurements used to benchmark the calculations being produced by the University of Virginia under RP492-2. *Mathematical Applications Group, Inc.*

Characteristics of pipe system failures in LWRs

NP-438 Topical Report (RP705-1)

This report is one of a series on nuclear power plant availability and reliability. It presents a statistical description of pipe system failures as derived from reports submitted by the utilities to the Nuclear Regulatory Commission.

The study emphasizes trends in the incidence of pipe failures and a statistical characterization of the failure events, including impact on plant availability and capacity. Pipe system failures are compared from the standpoint of frequency of occurrence within plant types (PWR versus BWR, frequency of occurrence within plant subsystems, failure modes, pipe size categories, and time-to-failure from initial criticality). Hypotheses regarding differences between frequency distributions with PWRs versus BWRs are tested via standard nonparametric statistical methods. *Science Applications, Inc.*

Dynamic modeling of a Mark II pressure suppression system

NP-441 Key Phase Report (RP693-1)

This report reviews a study via scale-model experiments of the dynamic response of a Mark II pressure-suppression system during the early air-discharging phase of a postulated loss-of-coolant accident. Tests using a 13.3-scale model produced quantitative information on the vent-clearing process, pool swell, wet-well pressurization, and many other dynamic responses of interest.

Corresponding information for the reference plant from which the model is scaled can be obtained from the test results and the scaling loss derived in the report. *Stanford Research Institute*

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