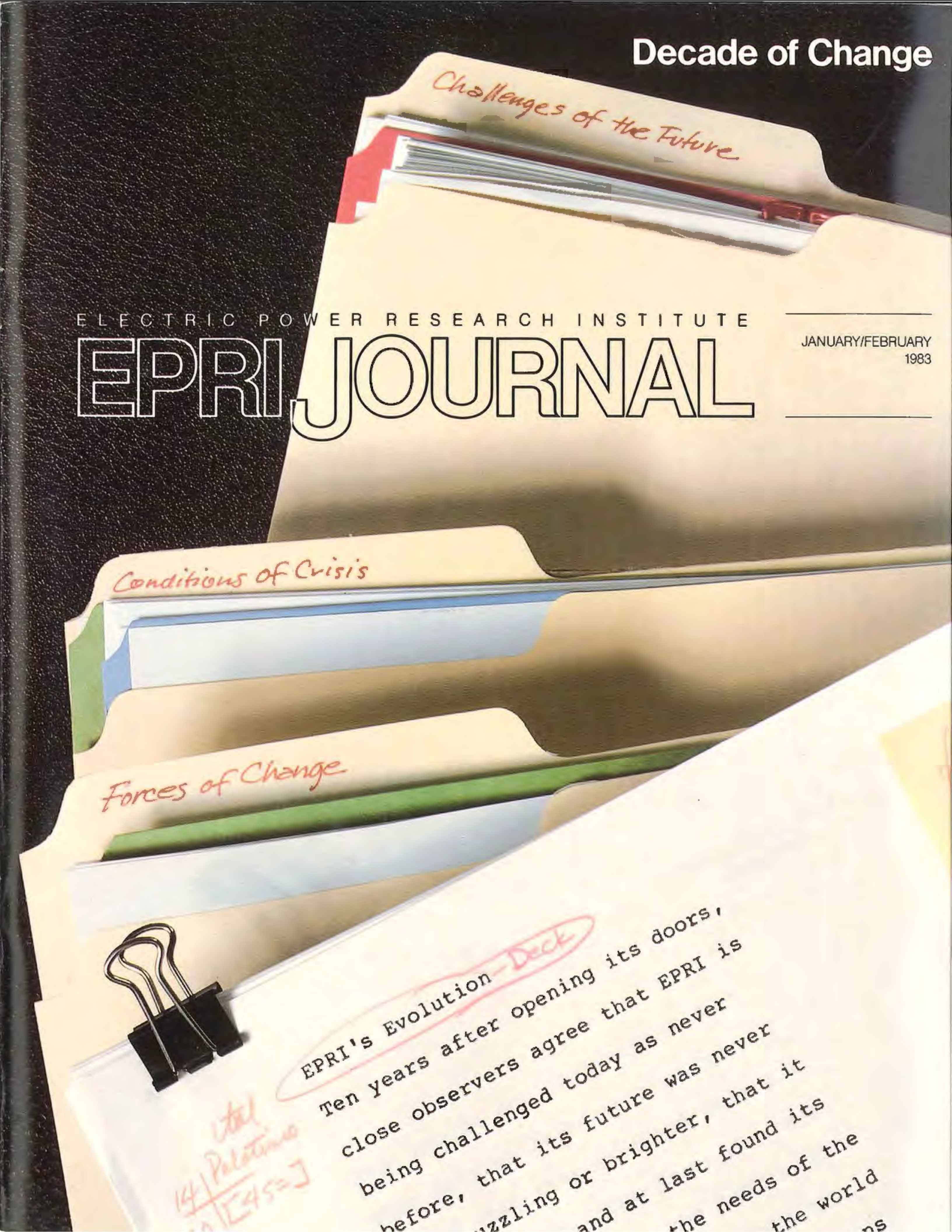
Decade of Change

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

JANUARY/FEBRUARY 1983



EPRI JOURNAL is published monthly, with the exception of combined issues in January/February and July/August, by the Electric Power Research Institute. The April issue is the EPRI *Annual Report.*

EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

EPRI JOURNAL Staff and Contributors
Brent Barker, Editor in Chief
David Dietrich, Managing Editor
Ralph Whitaker, Feature Editor
Nadine Lihach, Senior Feature Writer
Taylor Moore, Feature Writer
Pauline Burnett, Technical Editor
Marilyn Bishop, Production Editor
Jim Norris, Illustrator
Jean Smith, Program Secretary
Ellie Hollander (Washington)
Dan Van Atta (Public Information)
John Kenton (Nuclear)

Graphics Consultant: Frank A. Rodriquez

Ray Schuster, Director
Communications Division

Address correspondence to:
Editor in Chief
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

Energy events of the past decade have altered the economics of the electric utility industry and the priorities of EPRI's research.

EPRI JOURNAL

Volume 8, Number 1 January/February 1983

Features

Departments

Technical Review

R&D STATUS REPORTS

Authors and Articles

Evolution—the process of orderly, incremental change—can take millions of years to become apparent in the biological world, but such progress in human events and organizations is more likely to be seen in terms of decades. Brent Barker, the *Journal*'s editor in chief, finds a clearly evolutionary pattern of energy events linking the world, the electric utility industry, and EPRI itself since 1972. Barker's article, **Decade of Change: EPRI and the Climate for Research** (page 4), measures more than EPRI's growth; many people familiar with EPRI's beginnings shared their views on progressive changes in the Institute's orientation, scope, and mission.

Barker has been with EPRI since June 1977, when he became editor of the *EPRI Journal* after four years as a writer and communications consultant. Previously, from 1968 to 1973, he was with SRI International as an industrial economist, researching and writing on emerging technologies and industries. Still earlier, he was a research analyst for U.S. Steel Corp. Barker graduated in engineering science from Johns Hopkins University, and he earned an MBA at the University of Pittsburgh.

■

Properly known as a thyristor, the silicon-controlled rectifier was adapted for high-voltage ac-dc power conversion on utility transmission systems 10 years ago. Now **New Solid-State Valves for HVDC** (page 14) explains advances in switching and cooling that should make the big solid-state devices economical and reliable for wider use at higher voltages. The article was developed by John Douglas, science writer, who drew on the expertise of EPRI's Narain Hingorani and Gilbert Addis.

Hingorani, manager of the Transmission Substations Program, has guided HVDC research for the Electrical Systems Division since October 1974. He was previously with the Bonneville Power Administration for six years, working on the 850-mile (1370-km) dc link between northern Oregon and southern California. Before coming to the United States, Hingorani held research and teaching positions at three universities in England. He graduated in electrical engineering from the University of Baroda (India) and earned MS and PhD degrees in HVDC power transmission at the University of Manchester (England).

Gilbert Addis is a project manager in the Transmission Substations Program. He came to EPRI in September 1978 after 8 years as director of engineering for two different manufacturers of connectors. For 28 earlier years, Addis was a research chemist and technology manager for American Cyanamid Co. and Union Carbide Corp., successively. He has a BSME degree from Stevens Institute of Technology and a PhD in chemical engineering from Johns Hopkins University.

■

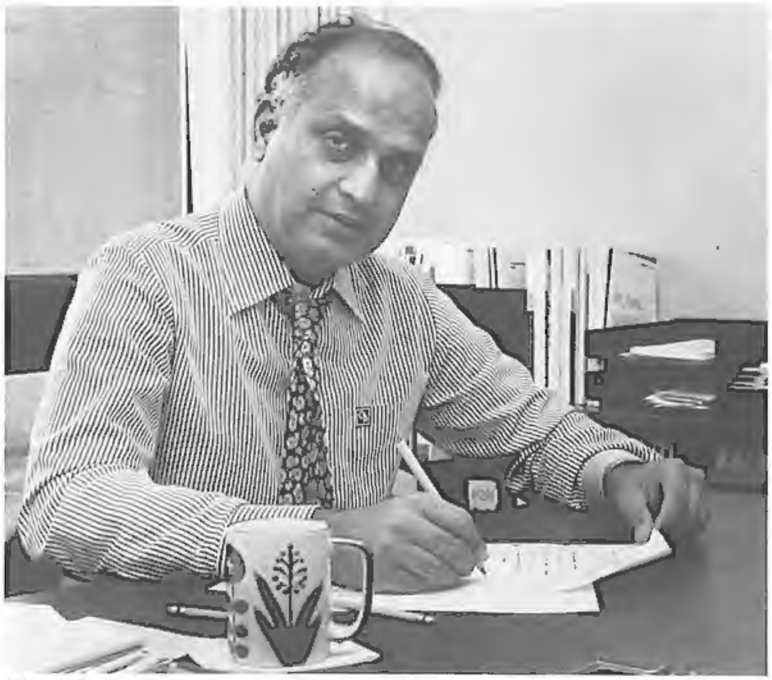
Perhaps because every one of us has burned a pile of trash somewhere, sometime, it seemed certain that utilities could easily burn municipal solid waste or refuse-derived fuel to produce some bargain-rate electricity. When that did not happen, we were disappointed. But utilities, developers, and communities have persisted, and **Megawatts From Municipal Waste** (page 20) summarizes the main lessons learned. Nadine Lihach, the *Journal*'s senior feature writer, turned to Charles McGowin for background.

McGowin is technical manager for analysis in EPRI's Coal Combustion Systems Division, responsible for both technical and economic evaluations of fossil fuel technologies; he also manages the division's municipal solid waste projects. Before he came to EPRI in November 1976, he was a senior research engineer with Shell Development Co. for seven years, part of that time specializing in raw material and recovery methods. McGowin graduated in applied science from Lehigh University. He also has a BSChE from Lehigh, and he earned an MS and a PhD in chemical engineering at the University of Pennsylvania.

■

Fast-growing street trees help sell houses in new developments, but trimming them becomes a frequent and expensive bother for the electric utility whose lines share the same airspace. **Controlling Tree Growth** (page 26) reports on the development of chemical treatments that retard both the rate and the luxuriance of growth for many trees. Science writer Rosalyn Barry turned to Robert Tackaberry for the major findings from 10 years of EPRI-sponsored research.

Tackaberry joined the Distribution Program of the Electrical Systems Division in February 1976. He was previously with A. B. Chance Co. and Joslyn Manufacturing & Supply Co. for a total of 24 years, successively in sales, applications, and marketing assignments. Tackaberry graduated from the U.S. Naval Academy and served in the Navy for 9 years.


Hingorani


McGowin


Barker


Addis


Tackaberry

DECADE OF CHANGE: EPRI and the Climate for Research

by Brent Barker

Ten years after opening its doors, close observers agree that EPRI is being challenged today as never before, that its future was never more puzzling or brighter, that it has recently and at last found its proper niche, that the needs of the industry, the nation, and the world will likely pull it into positions of technical leadership it never sought, and that were it to die suddenly, it would have all been worthwhile, one of the bright, bold institutional experiments in collective research and development—one already sufficiently successful to have become something of a role model for other highly diverse industries.

Few people feel as comfortable speculating on a course for the Institute's second decade as they did for the first. They have seen EPRI evolve not only beyond what they originally envisioned but beyond what they expected only a few years ago. Everyone, it seems, has learned through the tumult of the last 15 years not to take the future for granted; when it comes to the affairs of energy, reality can and does change its face abruptly. This lack of clarity about the future has been one of the most compelling lessons of the past decade for energy planners. It has also been one of the most painful and challenging lessons to an industry whose horizon for planning is traditionally measured in decades rather than years and whose vision of the future as late as 1970 was built on some 40 years of predictive certainty.

Forces of Change

The tranquility of the golden era about to pass

The period 1930–1970 is now often thought of as a golden era for electric utilities, a time when business was considered low-risk, when planning and regulatory affairs were relatively straightforward, when capital and fuel were readily available, and when one simply charted a course of constant per annum growth and went out and built. Electrical load would predictably double every 10 to 15 years, customers' rates would continue to fall as a result of improved efficiency and economies of scale (as they had since 1900), political issues would remain at only the nuisance level, and those environmental and resource issues just beginning to loom would eventually succumb to the benign blessings of nuclear energy, which would come to dominate electric power generation by the turn of the century.

By 1970, of course, change was in the air. The New York blackout, although five years past, had produced a sense of public vulnerability, bringing a new level of criticism and congressional scrutiny—scrutiny that seemed to linger on.

Environmentalism, simmering for decades as a reaction to the dark side of industrial progress, seemed to take sudden root in the secure soils of postwar affluence. The National Environmental Protection Act was passed in 1969, providing an outlet for what had become a broad and powerful sentiment in America to ease up on the subjugation of nature—and opening, as it were, an emotional and legal haven, a common rallying point for the various banners of ideologues and social protesters casting about for a fresh and just cause.

And last, impelled by the chaos of the 1967 Arab-Israeli war, the oil-exporting nations of the Middle East began to coalesce, openly speculating about the oil weapon at their disposal, one whose potency was assured by the peaking of U.S. oil production in the early 1970s.

These were to become the driving forces that would in a few years quickly politicize the world of energy and would by the end of the 1970s fuel the countervailing spirals of inflation and recession, utterly transforming the economics of the electric utility industry and the priorities of its new research institute. Some energy planners and industry leaders in 1970 saw these forces coming, and some could even imagine their combined impact. But for most, there was good reason for skepticism, not the least of which was the inertia of that golden era, a backdrop that seemed to render new problems as probably temporary or trivial.

Formation of EPRI

EPRI was thus brought into being not so much as a technical buffer against the gathering storm of the energy crisis, but rather as a hedge against the prevailing perception of nearly unlimited growth in the future of electric power. The technical problems of a vastly expanding, increasingly complex and systems-oriented industry had been accumulating for decades and were growing beyond the capability of traditional vendors to handle alone. And the advanced generation systems that could meet continuing geometric growth in consumption well into the twenty-first century, such as breeders and fusion reactors, would require greater technological efforts and a longer commitment than commercial vendors could be expected to make. The industry simply needed to take its future into its own hands.

Nearly a decade of persuasion and analysis by farsighted industry leaders preceded EPRI's incorporation in 1972.

"EPRI's emerging role—one that none of us expected—is to be one of the more constant forces in energy R&D in the United States. Our constancy is providing an element of stability in the totally politicized field of energy development."

—Floyd Culler

Joseph Swidler, as chairman of the Federal Power Commission in 1963, was the first to broach the idea. Addressing the members of the Edison Electric Institute (EEI), he said, "The nation's number one industry can afford a research program scaled to its needs and opportunities; it cannot afford the risk of lost opportunities and delayed progress that is inherent in the present lack of system or direction in research. . . . I should like to propose a small step that could lead to some improvement." Swidler's small step was a committee to consider a permanent industrywide organization.

This was a vital first step in consolidation. The Electric Research Council (ERC) was created within two years and in 1971 brought forth a report on the research needs of the industry. Called the Green Book, the study pointed to the need for $30 billion worth of R&D by the industry, manufacturers, and government over the next three decades, and recommended the establishment of a successor organization—a permanent, professionally managed institute. The industry was taken aback by the sheer size and ambition of the R&D effort that was being proposed.

Achieving consensus in an industry as heterogeneous as the electric utility industry, with some 3500 entities divided by geography, tradition, and vast differences in size and philosophy of ownership, is never easy or quick. Eventually, it is probably fair to say, the wisdom and practical benefit of EPRI would have prevailed over the initial reluctance of cost-conscious utility executives. But the point is academic; the debate was cut short by the very real threat of federal intervention.

Legislation was proposed by Senators Magnuson and Hollings to create a federal R&D agency supported by a 1% tax on utilities. Having done their homework, representatives of the industry were able to walk into the Senate Commerce Committee in March 1972 with a credible plan of their own (based on the work of the ERC) and to win a year's stay in order to establish a new electric power research institute. Shearon Harris, then chairman of EEI, Charles Luce, chairman and chief executive officer of Consolidated Edison Co. of New York, and George Bloom, president of the National Association of Regulatory Utility Commissioners, were the people most instrumental in gathering support and funding and in finding that key individual who could put it all together.

Chauncey Starr, then dean of the School of Applied Engineering at the University of California at Los Angeles, seemed exceptionally well matched to their prescription for "an internationally respected scientist with uncommon administrative ability." As founding president, Starr opened EPRI's doors in 1973 and set about building the Institute from the ground up with his usual entrepreneurial vigor. In line with his own prescription for great research—"great people and lots of money"—he located top research talent, drew them to the Institute, and gave them considerable freedom in shaping their own programs. Most of these people are still there. And today, outsiders as well as insiders agree that one of Starr's greatest legacies is the intellectual integrity he instilled into EPRI through his choice of staff and their staffs in turn.

Mission and adaptation

At the outset, it was assumed that the new institute would work on a relatively small number of large, long-range projects. This was in part due to the industry's concern that EPRI not duplicate or compete with the product development work of the commercial vendors, for fear of undermining their incentives to pursue R&D. The intention was to complement the work of others (manufacturers and government alike), to cooperate in the exchange of technical information, and, where expedient and practical, to join and cofund major development projects. The notion of pooled resources was thus extended a step further. Cooperative agreements were struck almost immediately with federal agencies doing related research, which led to an increasing number of jointly planned, funded, and managed projects.

Significantly for EPRI's evolution, there was built into the new organization a form of adaptive intelligence through the creation of an elaborate advisory structure. This set of committees with their hundreds of participants from the industry, known collectively as the Industry Committee Structure, helped to tether EPRI to the real world and to ensure continuous scrutiny of research progress and priorities by the ultimate users of the new technology. Many still regard this as one of EPRI's most ingenious and significant organizational elements.

New ideas, directions, and opportunities were carried home by the participants for yet broader review and familiarization, and new problems and needs were inevitably brought back and fed into EPRI's thinking. The trick was to maintain an organization that was informed and responsive, yet strong enough not to let its advisers supplant the judgment of its own research planners and managers. The balance, from the viewpoint of most observers, has been well struck; but all agree it was probably inevitable that such an adaptive organism would be progressively drawn from its long-range emphasis toward the whirlwind of immediate problems that had come to beset the utilities by the mid 1970s.

Also critical to the Institute's adaptive structure was a second advisory body created in EPRI's formative years, one that drew on the insights of individuals outside the industry itself. The spectrum of backgrounds ranged from science and business to education, labor, environment, and government; a number of public utility commissioners were specifically included. Known formally as the Advisory Council and informally as the "conscience of EPRI," this group more than any other is credited for impressing upon EPRI management in its first few years the seriousness and breadth of public support for the environmental and conservation movements. These were here to stay and must be dealt with, the Council members concurred.

Environmental assessment and control technology became one of the first and ultimately most striking departures from EPRI's anticipated mission. It was not initially a high-priority item on EPRI's agenda. David Saxe, EPRI's vice president for finance and operations and one of the first people to be recruited by Chauncey Starr, reflects, "It is rather surprising from where we sit now to think that back in those early days of EPRI, the need for an environmental program was not broadly recognized. Of course, now it receives a tremendous emphasis in the overall work of the Institute. . . . As much as 50% of our R&D is now driven by matters of environmental protection, health, and safety."

Conditions of Crisis

Energy shocks, economic upheaval, and their aftermath

EPRI was just settling into its new Palo Alto, California, headquarters, assembling its core staff and contract machinery, and putting its first programs into place when the oil weapon was unleashed in the winter of 1973-1974. The oil embargo lasted several months, sending motorists into long lines, foreign policy and energy strategists into long conferences, and the spot price of oil to about $12 a barrel, an overnight increase of approximately 400%.

Energy, once a backwater of public concern, suddenly became a front-page affair, taking on the proportions and trappings of crisis. The term stuck and was reinforced daily as the public watched the inflationary bulge of oil beginning to work its way through the economy, as they listened to the dire pronouncements of resource exhaustion and growth limits recently put forth by the Club of Rome, and as they watched in horror the capital resources of the western world flowing off to build the capital cities of the OPEC nations.

As the thought settled into something approaching certainty and conviction that oil would be in permanent short supply and that oil prices would constantly escalate over and above the inflation they helped to drive, the alarms of crisis began to turn the wheels of government. Presi-

"The fundamental premise of the 1970s panic-type reaction was wrong. It's all a matter of price, not a matter of running out. Based on my thinking now, oil prices will be stable in real terms throughout the rest of the century."

—Bruce Netschert

dential calls were made for energy independence and the moral equivalent of war-time mobilization. Disparate pieces of the energy establishment were assembled into the Energy Research and Development Administration, which in turn was elevated to cabinet-level status with the creation of the Department of Energy (DOE). Funding mushroomed for the development of politically popular alternatives—synfuels, renewable resources, and conservation—as the nation scrambled to reduce its dependence on the volatile regions of the oil-producing Middle East.

Although oil prices had stabilized at about $13 a barrel by the mid 1970s, analysts expected them to climb steeply in the next few decades, averaging perhaps 3–5% above inflation annually. Utilities began to backpedal, reversing the trend toward oil and away from coal that had been spurred only a few years before by environmental concerns. While high fuel prices were reluctantly passed through to the ratepayer, breeding considerable hostility and helping to politicize the utility world, they also made utility R&D more imperative. Higher costs served to improve the economics of competitive technologies and thus opened the future to a wide range of options, from solar to synfuels. By 1976, for example, it appeared that coal-derived liquids could be introduced in the early 1990s at about $45 a barrel (in 1980 dollars), which was at the time competitive with the projected price of crude. Coupled with the very real fear that in an emergency petroleum fuels would be cut off from the industry, this proved to be a powerful incentive for EPRI's push into the liquefaction area and its participation in joint research on several advanced processes.

Broader and larger

By the late 1970s, EPRI found itself considerably broader and larger than its architects had envisioned. Its programs were becoming increasingly skewed toward the near term, requiring more projects, an expanding project management load, and increasing interaction with utilities. Project results and reports began flowing out at a rate that exceeded any existing mechanism for assimilation by the industry. Thus one of EPRI's new challenges became how to communicate more effectively with its members.

The Institute was by this time linked with many other organizations in a growing array of cooperative development activities and information exchange agreements. It was also moving beyond its original hardware orientation into computer codes, decision-making tools, environmental assessments, and strategies for load management and conservation. It was following through into the commercial phases of new and promising technical developments, such as fuel cells and gasification-combined-cycle plants. It was establishing test centers to focus engineering development activities for batteries, emission control devices, nondestructive evaluation, underground cables, coal cleaning, and UHV transmission. And it was responding to a growing number of urgent technical problems brought to it by the industry. Several owners groups were created, and in 1979 the Nuclear Safety Analysis Center was formed within weeks of the Three Mile Island accident.

EPRI's gravitational drift toward the more immediate problems of the industry was accelerated by a series of new shocks beginning in 1979. The revolution in Iran removed some 3 million barrels of oil a day from the world's supply and doubled the price to $30 a barrel. This sent another jolt through the already weakened economies of the world and left some of the Third World nations teetering on the brink of bankruptcy. At the same time, interest rates soared to historical highs, curbing investment and credit and setting the stage for a prolonged recession.

Conservation activities, under way in many sectors of the U.S. economy for years, were spurred on by the new movement in fuel prices but, when combined with the recessionary spiral, produced a near collapse in the historical rate of growth in electrical load. Electricity demand, for all practical purposes, would soon cease to grow for the first time in history, leaving industry planners with a murky view of the future and a reduced justification for expansion. Plant cancellations, on the increase for several years, picked up appreciably, leaving the future of the industry more and more dependent on the existing fleet of aging plants.

And in a similar vein, Three Mile Island, while a watershed event for the nuclear industry, brought home to all the utilities in the land the larger message of the financial exposure they faced from the failure of large technological systems, a realization that underscored the importance of the technological health and welfare of their current systems. Improvements in plant availability, reliability, and preventive maintenance were assigned higher priority.

Policy and price shifts

Two further events collided in the early 1980s to take much of the steam out of energy development that had built up over the previous six or seven years. Oil prices stabilized in a sudden unpredictable glut of oil. And the new administration, in line with its philosophy of appropriate private and public sector roles and its intention to dismantle DOE, drastically cut the funding for those aspects of R&D associated with conservation and the commercialization of synfuels, solar, geothermal, and wind. Large-scale, expensive demonstration projects in which the government was a major participant were suddenly in jeopardy. The private sector had insufficient funds and incentive to fill all the gaps and began to prune away the least attractive options and stretch out the more attractive ones. In the sudden turnabout of price and policy, the incentives for synthetic liquids seemed to dissolve overnight, and major projects—from the Exxon Donor Solvent process to oil shale—were dismantled.

Despite forewarning, the reversal of federal policy left many energy planners and managers stunned and frustrated. Even those in complete philosophical agreement with the administration saw the folly of such boom-bust federal support and periodic policy reversals in an area requiring commitments stretching over decades. Given the political realities of government, many people both here and abroad became wary, wondering whether the U.S. government could ever again be a reliable partner in long-term energy development.

This has left EPRI, by default, in a new position. "EPRI's emerging role—one that none of us expected—is to be one of the more constant forces in energy R&D in the United States," says EPRI President Floyd Culler. "We can maintain an attention span and funded development somewhat unperturbed by the biennial political shifts. Our constancy is providing an element of stability in the totally politicized field of energy development."

Crisis redefined

Oil remains the benchmark of energy—acting as a price leader for other fuels, setting the competitive targets for energy technology development, and, to an extent yet unknown, driving the oil-consuming and -producing economies of the world. Whereas the 1970s were characterized by an imbalance between these economies, the 1980s thus far point to a new reality—or a new illusion—that the balance has been righted.

There is a sense today that the energy crisis has transformed itself after 10 years of high drama back into the chronic energy problem it always was. The world simply reacted much more quickly and massively to OPEC price increases than anyone anticipated. Demand for oil has been cut sharply by conservation activities and worldwide recession, and new sources have been progressively brought in from the far reaches of the earth. OPEC presently has a surplus capacity of 11 million barrels a day—twice the cur-

"Certainly as far as the electric power industry is concerned, I don't believe there has ever been a time when the industry has been more interested in not building plants than in building them."

—Sam Schurr

rent production rate of Saudi Arabia—and real prices of oil have dropped by some 20% in the last two years.

Bruce Netschert, vice president of National Economic Research Associates, Inc., and a former member of EPRI's Advisory Council, believes that "the fundamental premise of the 1970s panic-type reaction was wrong. It's all a matter of price, not a matter of running out. Based on my thinking now, oil prices will be stable in real terms throughout the rest of the century. They will not go up—or at most 1% a year."

Others are hesitant to consider price stability, pointing to the whipsaw potential of any commodity and the particular surprises of oil in the past few years. There is even concern now about a possible price collapse that could endanger recent investment in deep drilling, secondary recovery, and some alternative oil technologies. "To understand just how soft the underlying oil price is," says Llewellyn King, publisher of *The Energy Daily*, "you have to realize that we have had an extraordinarily bad year internationally—I think the State Department counts eight wars—without price escalation. Remember, the Iran-Iraq war initially pushed the spot price to $50, but now it's under the posted price."

If oil prices have in fact stabilized for the long term and conservation has been irrevocably set into motion in all sectors of the U.S. economy, then it would seem likely that in the 1980s energy will recede as an issue unto itself—that it will turn the stage over to the larger economic issues it helped to create or to illuminate, including productivity, efficiency, and the preservation of capital.

Challenges of the Future

Responding to the emerging needs of industry and society

The state of affairs of the electric utility industry in the 1980s is not good, and the tumultuous events of the past decade have brought great financial pressures. The cost of construction and the cost of capital, for example, have risen to the point where large new plants can exceed the asset value of the company. Environmental regulations have compounded to the point where effluent control equipment can represent 50% of the cost of a new coal-fired power plant. And for the first time since the Depression, no new large baseload plant of any kind was ordered this past year; nor were any large turbines.

Pressed for funds, utilities are taking a much harder look at the return from their investments in R&D. This has put renewed emphasis on how EPRI divides its attention among the current generation of plants, the next generation, and the generations beyond. This relationship of near-, mid-, and long-term R&D has evolved over the past decade from roughly 50-40-10% to 70-25-5% today. Some close observers worry that continued pressure for near-term results might eclipse the mid- and long-term needs of the industry, that short-term thinking might harden into shortsightedness toward exploratory research. But most feel the risk is manageable and prudent for the times, and that EPRI has found its proper niche in the scheme of energy and utility R&D.

In principle at least, this is compatible with the position of the federal government. "EPRI, sitting much closer to the user and the supplier," says George Keyworth, science adviser to President Reagan, "is in a better position than the government to set priorities in the development and demonstration of new technologies."

Today, EPRI's $300 million a year R&D program is one of the most diversified energy programs in the world. In its first decade, the Institute initiated some 2000 projects and awarded some $1.5 billion in research contracts. In the next five years, it plans to award an additional $1.8 billion and, through cofunded and cost-shared projects with contractors and other organizations, to make available to its industry sponsors the benefits of another $1 billion in R&D funds.

This represents a sizable investment. Yet these research expenditures appear small when compared with the size of the sponsoring industry. Annual revenues for EPRI account for about one-third of 1% of industry gross revenues; and the cumulative 10-year R&D expenditures to date represent about one-tenth of 1% of the current estimated replacement cost of the entire U.S. electric utility system, which is on the order of $2 trillion, or comparable to the U.S. gross national product for one year.

This points to the enormous financial leverage that technical improvements of the smallest kind can exert on the most capital-intensive industry in the nation—one that typically consumes more than 10% of U.S. nonfarm investment. The scale is such that if outage rates for coal and nuclear plants could be reduced by 1%, the utilities could save some $2 billion over the next five years.

Technology transfer

Few now doubt the potential of utility R&D, but after 10 years many are openly concerned about realizing the payoff. Research results are simply not moving fast enough or pervasively enough into the utility systems on a routine basis, despite the intricate communication channels of the advisory structure, the publication of some 2400 technical reports, the profusion of seminars and workshops, a computerized information system, and greater availability of staff. There is a broad consensus that technology transfer is EPRI's most urgent problem and conceivably its greatest and most fundamental challenge for the 1980s.

Joseph Swidler, who first called for EPRI 20 years ago, now says, "EPRI has a distance to go. The staff has become a primary technical resource for the whole industry—and in my view this alone justifies its existence—but the area of technology transfer is still, to my mind, imperfectly coordinated. EPRI ought to work more closely with various labs, manufacturers, and groups of user companies to tighten that whole complex of relations. Market tests should be applied at every stage, and emphasis put on those things that have potential for early acceptance."

Ruth Davis, former assistant secretary of DOE and former chairman of EPRI's Advisory Council, has been exploring technology transfer among many companies. "EPRI is late, but not too late," she says, "in recognizing the importance of giving very high priority to the mechanism for transferring technology. It's going to mean getting down and really digging. It's always difficult and never fun. I've seen too many scientific and engineering organizations fade away as they gave up on this."

By 1981 EPRI's technical divisions had been assigned the lead role in transferring technology, and a new group had been consolidated to coordinate and strategically direct the flow of information to facilitate technology transfer. Ric Rudman, director of the Information Services Group, describes the attitude of industry as shifting from "a consideration of R&D as an insurance policy to that of an investment. With insurance, one tends to forget it after purchase, but with an investment, there is a continuing need for justification. How good is my investment? How is it doing? What is my return?"

No one doubts the challenge. Technology transfer has never worked on the grand scale of dispersion that EPRI is about to try—at least to anyone's knowledge. Where it has worked well, Davis points out, there is good vertical integration, very strong pressure from senior management, and a close coupling between operating arms and laboratories. This prescription of highly directed transfer would seem at odds with the voluntary links between EPRI and its members; thus utility receptivity and incentives to foster receptivity will become critical issues for the long term.

For the immediate future, information flow is a key strategic element. EPRI is now embarking on a system to target the right information to the right person in 600 different utilities—each with its own system of communications, organization, technical capability, and priorities—and once the information is there, to make its significance immediately clear and compelling.

"EPRI is late, but not too late, in recognizing the importance of giving very high priority to the mechanism for transferring technology. I've seen too many scientific and engineering organizations fade away as they gave up on this."

—Ruth Davis

One of the more tangible concerns facing EPRI in the area of technology transfer is how to bridge the gap between product readiness from the researcher's point of view and from the utility operator's point of view. Some of the application engineering and market development issues involved are now being explored at EPRI's test centers, such as the Nondestructive Evaluation Center in Charlotte, North Carolina, where the researcher can meet with the utility engineer or technician to discuss design, operation, field use, and training.

One of the more elusive concerns is the front-end cost barrier to technology transfer. Because of the financial pressure on utilities, even things that could help are deferred. "Many utilities," says Rudman, "are in a position of having to say 'our number one problem is cash flow, and we're not going to do anything to exacerbate it.'"

Program plan

Through the late 1980s, EPRI's base program of R&D is designed to respond to the industry's critical near-term issues—from flexibility to minimizing the need for capital. "Flexibility to maneuver in these tight times," says Richard Balzhiser, vice president for research and development, "means being able to cope with a high degree of uncertainty. And this in turn means improving our forecasting, improving our load management strategy and equipment, providing modular generation alternatives, supporting conservation, stretching out the life of our plants to give us some breathing room, staying out in front of emerging issues, and keeping our largest and most dependable resource options—coal and nuclear—open."

The high cost and limited availability of capital have had profound research implications. Sam Schurr, economist and deputy director of the Energy Study Center at EPRI, says, "Capital scarcity was a problem back in the early days of our country. But the present situation is unmatched, I think, in earlier experience. Certainly as far as the electric power industry is concerned, I don't believe there has ever been a time when the industry has been more interested in not building plants than in building them."

This has several implications for research. One is the need to extend the life of existing plants by upgrading components, improving operations, and moving toward the use of diagnostics to prevent catastrophic failure and fine-tune the maintenance functions. Another implied need is to extend baseload capability through conservation and load management strategies and technologies.

Capital preservation can also be accomplished by building new systems with higher availability and reliability, and one route to this is through the use of parallel, modular generation units as opposed to a single large system. Building in modular units has assumed greater importance in these times of uncertainty. It could provide the means to add small increments of capacity more quickly as load growth becomes apparent. Construction times are more typically 3 to 5 years than 10 to 12. Sizes can vary from a few megawatts to a few hundred, and the technologies range from gasification-combined-cycle and fluidized-bed plants to renewable resources and fuel cells.

Another trait common to these new technologies is their inherent cleanliness. Environmental compatibility is now a prerequisite for new power generation technologies and, in fact, is one of the key criteria in screening options for development. Existing plants represent a more controversial situation. With the slowdown in new plant construction and plant turnover, environmental progress has also been slowed in the eyes of environmental pressure groups and their constituents, who as a result see a need to shift their strategic focus from new plants to retrofits on the existing fleet.

Environmental issues facing the industry in the next decade include acidic deposition, carbon dioxide, electric field effects, and solid waste. The concern over acidic deposition is considered by some to be the culmination of a 15-year series of air quality actions. As the legal focus expands beyond atmospheric loading to include terrestrial loading, solid waste is expected to emerge as a major environmental issue.

Expanding horizons

Looking ahead, most observers feel that EPRI will experience great pressure to expand its current scope of activities, and that one of the central, ongoing challenges to EPRI's management, Board of Directors, and advisers will be to constantly reevaluate the Institute's proper boundaries. Inevitable tensions will arise out of the fact that EPRI is widely regarded as a premier technical resource and the fact that the operational, engineering, and research needs of the industry far exceed the Institute's resources. There may be increasing temptation to turn to EPRI for consultation and support in matters well beyond those of R&D.

How far EPRI can go in devoting resources to the transfer and commercialization of technology is today the clearest manifestation of this concern about boundaries. The need is apparent, even urgent, but an all-out response would seem to put the Institute at risk of diluting its resources. Transfer might require a nearly open-ended response, pointing logically toward a whole new class of information, marketing, business development, and perhaps even customer service activities.

Another broad area of possible expansion is what Chauncey Starr calls the "clinical functions . . . that class of activities where the emergency room is thrown open and in come the big events requiring an organized scientific and technical team." Three Mile Island was such an event. EPRI will continue to serve in a standby capacity for emergencies. But beyond this lies another large class of clinical activities more analogous to health maintenance than surgery. EPRI is in a prime position to coordinate and focus a great many technical resources onto a given problem, and in the extreme to take on a type of consultancy—that is, to pursue not only generic technical problems but those specific to a given client. Again, the inclination to be responsive poses the danger of opening the floodgates on EPRI's limited resources and perhaps undermining its longer-term development activities. Some balance is obviously required.

One important continuing course of expansion for EPRI is to move further into the vacuum of leadership in U.S. energy R&D to facilitate and/or integrate new cooperative ventures in advanced energy development and demonstration. The cost of demonstration is such that pooling resources up to and including the international level makes considerable sense, but there is always difficulty in pulling together and holding together such collaborations. In this regard many now look to EPRI as not only a catalyst but, in the words of Ruth Davis, "the mortar between the bricks."

Further leadership activity will likely include an entrepreneurial role in seeding new organisms of collective research. EPRI has established seven test centers and has contributed indirectly to several new ventures in other industries. It is also exploring the feasibility of application centers where research would be conducted on new electricity-based processes, such as plasmas, to enhance industrial productivity.

Leadership will also carry with it the responsibility of vision, and here EPRI is ideally suited to explore the long-range potential of electrification in the coming age of information, computers, robotics, service industries, and more efficient forms of industrial production.

Poised for its second decade, EPRI has taken new initiatives to secure the industry's investment in R&D and to maintain momentum in critical areas of development, such as gasification–combined-cycle and fluidized-bed technologies. Gerald Tape, president of Associated Universities, Inc., and former chairman of EPRI's Advisory Council, seems to summarize the sentiments of most close observers when he says, "As I look to the future, it is my hope that EPRI doesn't lose its initial spirit, drive, and flexibility, that it doesn't become overly invested in particular lines of research—that it remains out in front of the problems and moving with the times." ■

Background for this article was drawn from interviews with the following people: Ruth Davis, president, The Pymatuning Group, Inc., Charles Gray, assistant general counsel, National Association of Regulatory Utility Commissioners; John Kearney, senior vice president for energy and environmental activities, Edison Electric Institute; George Keyworth, science adviser to the President of the United States; Llewellyn King, publisher, *The Energy Daily*; Bruce Netschert, vice president, National Economic Research Associates, Inc., Joseph Swidler, senior partner, Swidler Berlin and Strelow; and Gerald Tape, consultant and past president, Associated Universities, Inc. EPRI staff interviewed for this article were Chauncey Starr, vice chairman, Floyd Culler, president; Milton Klein, senior assistant to the president, Richard Balzhiser, vice president for research and development; David Saxe, vice president for finance and operations, Richard Rudman, director, Information Services Group; Fritz Kalhammer, director, Energy Management and Utilization Division; René Malès, director, Energy Analysis and Environment Division; Dwain Spencer, director, Advanced Power Systems Division, Kurt Yeager, director, Coal Combustion Systems Division, Robert Loftness, director, Washington Office; Sam Schurr, deputy director, Energy Study Center, and Chris Whipple, technical manager, Energy Study Center

New Solid-State Valves for HVDC

Light-fired thyristors should significantly reduce the cost of ac/dc conversion, conceivably opening the door to wider use of HVDC transmission.

High-voltage direct current (HVDC) has several advantages over alternating current (ac) for carrying large amounts of electric power, but terminals for converting one to the other have generally been so expensive that HVDC was considered economical only for very long distance transmission. Now, improvements in the HVDC equipment, especially the electric valves that facilitate the conversion, are making HVDC transmission cost-effective over shorter distances. At the heart of this new technology is a light-fired thyristor and an evaporative cooling system for a large number of thyristors in a valve developed by General Electric Co. in cooperation with EPRI. The first large-scale demonstration of these improved thyristors is scheduled for 1983.

Thyristors are solid-state electronic devices that must be turned on, or triggered, to permit current to flow. Sometimes called silicon-controlled rectifiers, they can pass current in only one direction after being turned on by a triggering pulse. They turn off when the current returns to zero. Combinations of thyristors can be used to rectify ac current to dc or to invert dc to ac. Thyristors are also the key components in static VAR compensators that are used for ac voltage support in transmission systems. These compensators control the reactive power balance, thus improving the power transfer capability of the transmission lines.

Most of today's high-voltage thyristors are triggered electrically; this requires a separate circuit that must be carefully insulated from the main power transmission system. By using light to trigger the thyristors, engineers hope to make converter terminals less complex, reduce their cost, and improve system reliability and efficiency. The new evaporative cooling system will also allow the thyristors to operate under higher load conditions without overheating.

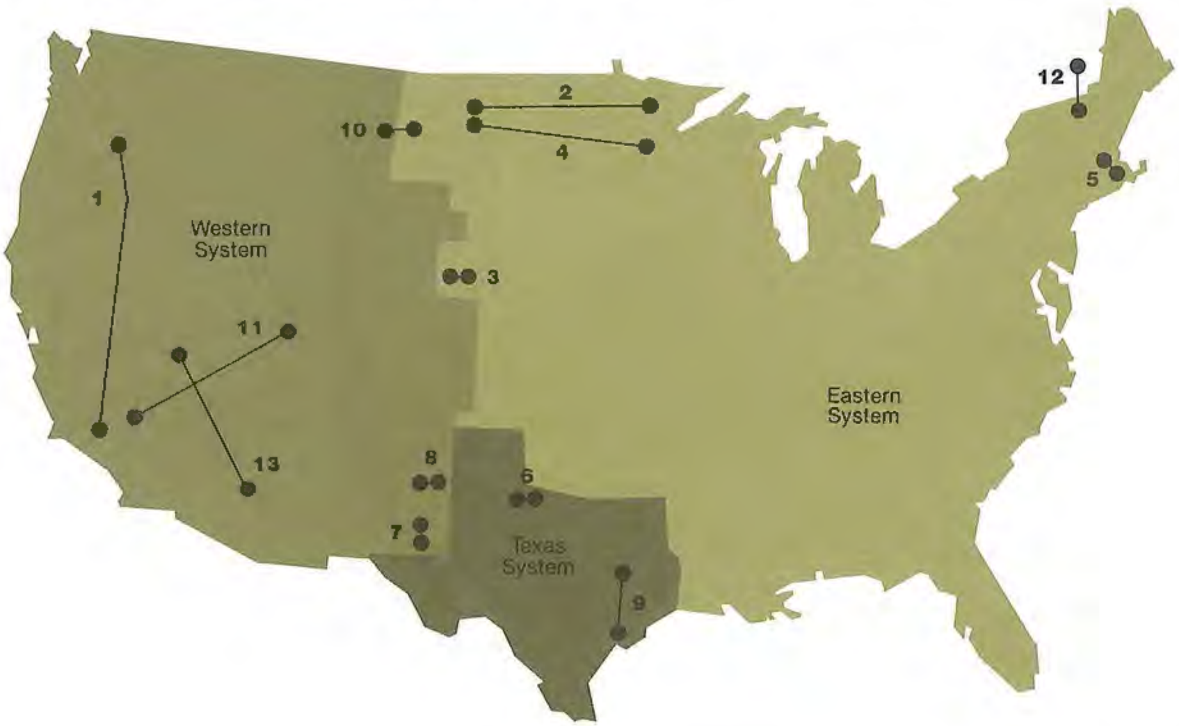
Solid-state valves

In the early days of electric power, the only way to convert one kind of current to another was to use some fairly clumsy electromechanical device—for example, having an ac motor drive a dc generator. Not only was this very expensive and inefficient but it also limited the resultant dc voltage to what could be produced directly by the generator. High voltages are needed in long transmission lines to reduce energy loss, but only ac can have its voltage raised by a transformer. Thus dc transmission lagged until the mercury arc valve was developed that could rectify ac after its voltage had already been raised. This valve worked something like a vacuum tube, except that it had ionized mercury vapor inside. The problem was that like vacuum tubes, mercury arc valves were expensive and bulky; in addition, they required costly maintenance as they aged.

Then in 1972, after nearly a decade of development, the first solid-state valve to be used in a commercial HVDC system went on-line at the Eel River converter station in Canada. The technology was an instant success. After this introduction of the thyristor to high-voltage applications, there was only one new installation of mercury arc valves. Through more research and development, solid-state valves became less expensive and more reliable, and their use resulted in less power loss in conversion equipment. Using thyristors, HVDC became competitive with ac transmission systems for distances exceeding about 400 miles (644 km) over land, or about 20 miles (32 km) of cable underground or under water. And where power systems were to be interconnected, very short HVDC links provided an increasingly attractive means of preventing instabilities or frequency shifts in one system from spilling over into the other.

Still, the present generation of thyristors has significant design limitations that have prevented even more extensive use of dc in high-power applications. Individually, these solid-state devices tolerate relatively low voltages of about 1–5 kV, compared with system voltages that may exceed 500 kV. Therefore, many thyristors must be connected in series to create an HVDC converter. Above all, thyristors must be prevented from overheating, which can occur during overload

HVDC projects in the United States in operation or proposed for initiation in 1983. In some projects, dc is used for efficiency in long-distance transmission; in others, where an ac connection is not feasible because of possible system instability or the need for independent control of each system, dc is used for power interconnection.



		Nominal Capacity (MW)	Date in Service
1	Pacific Intertie	1440/2000	1970/1985
2	Square Butte	500	1977
3	Tri-State	100	1977
4	Cooperative Power Association–United Power Association	1000	1979
5	EPRI Compact Prototype	100	1983
6	Oklaunion	200	1984
7	El Paso–Southwest Public Service	200	1984
8	Public Service of New Mexico	200	1985
9	Walker County–STP	500	1985
10	Miles City–Montana	200	1985
11	Intermountain Power Project	1600	1986
12	New England ETC–Hydro Quebec	690	1986
13	Phoenix–Lake Mead	1100/2200 (proposed)	1988
	Total	7830/9490	

or fault conditions or when a supplementary cooling system does not function properly.

Two important improvements

Projects being conducted by General Electric under EPRI Project Manager Gilbert Addis are designed to increase the capacity and reliability of high-voltage thyristors through two fundamental design changes.

First, instead of employing a separate electric circuit, conduction will be initiated by light conducted to each thyristor in a series by optical fibers. These glass fibers, of course, do not conduct electricity, so their use will greatly decrease the problems of insulating the triggering circuit from the power circuit. Also, they are more immune to interference and accidental firing from electrical noise generated by the switching of other valves in the converter circuit, which can cause accidental firing of thyristors activated by electric triggering circuits.

Second, a two-phase cooling system in which a liquid is vaporized to absorb greater quantities of heat will be able to replace other means of cooling. Such a two-phase Freon system will provide a much more efficient way of keeping thyristors within an acceptable temperature range. Using such a system will increase the current density that can be tolerated by the thyristors. It is also more compact—an important factor in keeping costs down.

The principle of triggering thyristors with light has long been understood, and such devices are already commercially available for low-power applications. However, these small photothyristors can use light sources placed in close proximity; for high-voltage converters, the two systems have to be separated. To reduce the requirement for insulation and to expedite repairs, the electrical equipment that controls the light source has to be shielded and at a distance from the main transmission circuit. That way, if redundant triggering systems are used, maintenance can be performed on one light source while the other continues to operate. By avoiding a shutdown of the whole converter terminal during such maintenance, a utility may be able to save as much as $100,000 an hour.

The search for a light source

EPRI has concentrated on two main choices for providing the needed source of light—laser diodes and cesium arc lamps. Both can be pulsed at the required speed, and each might be able to do the job under certain circumstances.

At first, laser diodes looked like a good candidate. They are very compact, give off particularly intense beams of light, and have been tested in another EPRI project aimed at developing an improved static VAR generator. The problem was that because their light-emitting aperture was so narrow, each diode could only trigger one thyristor. Therefore, hundreds of diodes and a complex network of very fine, relatively brittle optical fibers would be required to help operate a major high-voltage converter system with the required redundancy. For HVDC valves that require as many as 100 thyristors in series, estimates of the likely cost and potential unreliability led to work on finding a single lamp that could trigger hundreds of thyristors simultaneously.

Attention soon began to focus on a new low-pressure lamp General Electric was building that was similar to the company's popular Lucalox sodium arc lamp, commonly used for street lighting. The new lamp contained mainly cesium vapor and had a smaller bore that increased arc intensity. However, at first it appeared that very large peak currents (as high as 2000 A) would be needed to produce sufficiently intense light from these lamps to trigger thyristors at the end of 20-m-long optical fibers. Producing rapid current pulses of this magnitude would have been both very difficult and expensive. Fortunately, improved optical fibers became available, General Electric continued development work on the lamps, a small amount of mercury was added to increase light intensity, and the magnitude of required current was reduced to 300 A.

Flashing the lamps quickly and accurately is a demanding business that requires microprocessor control. Usually the lamps are required to fire steadily, once each cycle, but under certain circumstances (including startup and line emergencies) they may be pulsed up to four times per cycle. The microprocessor must therefore monitor conditions in the lamp and ensure that each pulse can be delivered at full strength. Lamp temperature and pressure are controlled by adjusting a keep-alive circuit, which provides a relatively small amount of current to maintain the cesium and mercury in plasma form. Additional current to create a brilliant arc is then provided by a pulsing circuit, which uses power thyristors to control discharge of a capacitor through the lamp.

To conduct the flashes of light from the lamp to the large, high-voltage thyristors requires fiber-optic light guides similar to those commonly used in medical examinations, but much more efficient. Rather than using the thin, easily broken fibers that have been used with laser diode light sources, more-sturdy fibers with diameters of 0.4–0.6 mm can be used. Made of drawn fused silica, these fibers cause very low loss of light and can be spliced if necessary. At the lamp, the ends of the fibers are arranged around the arc, from which they conduct light to the gate areas of many thyristors in a valve.

Improved cooling

An inherent part of boosting the power conversion capacity of thyristors is increasing the removal of heat caused by power losses within the thyristor assembly. While developing the latest generation of large (77-mm-diam) thyristors, General Electric also substantially improved the flow of heat from inside the thyristor package through the use of new materials and a process that changed the way electrodes were attached to the semiconducting material. It was then necessary to find a better way to move heat away from a thyristor's external housing so that large numbers of the device could be used in series, as required for high-voltage conversion.

When EPRI undertook to help fund development of an improved external cooling system, there appeared to be two possible alternatives to replace forced-air cooling. The first of these involved passing a liquid over the thyristor housing to carry heat away by simple conduction. The advantages of this method were its simplicity and availability. The second, more complex alternative was forced evaporative cooling, in which a liquid would boil on contact with a heat sink adjacent to the thyristors. Similar two-phase (liquid and vapor) systems are commonly used in refrigerators and air conditioners. Although such a system would require substantially more development work and would be more difficult to control, it was finally chosen because of its greater efficiency, compactness, and cost-effectiveness.

By allowing the liquid to boil, the cooling system could take advantage of the latent heat from vaporization of the liquid. The pumping rate for passing the cooling liquid past a thyristor would only have to be one-tenth as great if this latent heat of vaporization was absorbed than if the system relied solely on heat transfer to a nonboiling fluid. Not only does this lead to greater efficiency but it also helps prevent the buildup of static charge that can result when large quantities of liquid are pumped at high velocity.

As a result of using the two-phase system, more heat can be removed from the thyristors, allowing them to operate at a lower temperature. This helps provide an added margin of safety in case of accidental overload. In addition, the two-phase system uses Freon rather than water as its operating fluid, which means that leaks can be detected more readily, and leaking Freon fluid is not as likely to cause a flashover. In the long run, the more complex, evaporative cooling system was thus judged to be less expensive than the simpler one based on liquid cooling.

However, to develop such a system specially tailored for use in converter terminals required overcoming several technical problems. Some basic design limits could be drawn from the extensive experience gained with two-phase cooling systems in the chemical and nuclear industries, but the size and configuration of the present system were to be so different that extensive analytic modeling was also needed. Instead of the usual single path for the fluid to follow, a cooling system that serves multiple thyristors independently must have many tubes. These would have relatively small bores and run in parallel, so complex calculations were required to ensure adequate flow in all tubes.

Computer models developed by General Electric permitted extrapolation of the necessary data from experiments related to the cooling system design. Heat transfer between the heat sink and the coolant was measured and related to the overall efficiency of the system. Limits were set on the maximum amount of heat that could be transferred without drying out the tubes. Operational limits of the cooling system were correlated to the amount of heat that might be expected to be generated by power surges in the thyristors. Eventually, a 100% safety factor for adequate heat transfer was built into the designs, as were provisions for redundancy in pumping and for automatic shutoffs. An experimental model of the cooling system, based on the results of these calculations, confirmed their validity.

Demonstration in 1983

Before a technology of this type can be considered ready for market, it must be demonstrated on a commercial scale. Such a demonstration allows engineers to work the bugs out of a new system, while providing operating experience under a variety of realistic utility conditions. In the present case, General Electric is preparing one full-scale advanced thyristor valve, complete with the new light-firing and cooling systems. This device will replace an existing mercury arc valve at the southern end of the HVDC Pacific Intertie Line, now the country's largest dc transmission system. This demonstration, which is scheduled to begin during the fourth quarter of 1983, is also funded by EPRI. The host utility is the Los Angeles Department of Water and Power (LADWP).

The demonstration at the Sylmar converter station will take place over two years. The transition period between fall and winter, when net power flow along the Pacific Intertie is at a minimum, has been chosen for installing the advanced thyristor valve module. During this period, the Intertie can most economically be shut down to facilitate this sort of major installation. For the remainder of the demonstration, the valve will be subjected to several specific tests to be coordinated by EPRI and LADWP, in addition to being observed during normal utility operation.

Future directions

The advanced thyristor system developed by EPRI and General Electric marks an important step in the evolution of solid-state electronic valves for HVDC power transmission applications. Creation of a triggering system based on direct light-firing of thyristors should make it easier to stack thyristors in the large arrays needed to handle high voltages. And use of a highly efficient external cooling system with these thyristors will enable them to operate more reliably under increasingly strenuous individual load conditions. If the proposed demonstration of this new technology is successful, HVDC transmission should become even more attractive economically.

To make the system even more reliable and more widely applicable, another important improvement is being investigated. A way is being sought to make the light-fired thyristors self-protective, that is, capable of withstanding severe overvoltage without suffering catastrophic failure. If, for any reason, one thyristor in a stack should not receive a triggering signal or should turn on too late, voltage could build up across an individual device until current rushes through its weakest spot. To prevent this occurrence, which could destroy the solid-state material inside the thyristor, engineers are experimenting with a means of controlled overvoltage turn-on that would not be self-destructive.

The likely impact of advanced, light-fired thyristors on power transmission and the importance of EPRI's contribution to their development are summarized by Narain Hingorani, program manager of the Institute's Transmission Substations Program.

"Cost reduction in converter terminals is of great importance for increasing the use of HVDC. The largest potential for cutting costs is in the valves through increasing voltage and current capability, if it can be done without sacrificing efficiency, reliability, or other desirable characteristics. So far, our projects have increased voltages across individual thyristors from about 3 kV to 5 kV. In the future, we can foresee reaching 10 kV. These advances represent real cost savings. Development of light-fired 5-kV thyristors should reduce both capital and operating costs by as much as 20%; addition of improved packaging and cooling, another 15%. By the time we reach 10 kV, costs of converters may be cut in half.

"Such developments represent significant and extremely constructive risk-taking on EPRI's part. If we look back to 1974, light-fired thyristor technology was considered very risky for use in HVDC facilities. It took an organization like EPRI to accept those risks when no one else was willing. EPRI's ability to recognize this potential, together with the marvelous innovations created by General Electric engineers, is now paying off in a very attractive new valve that should find wide application in the HVDC field." ■

This article was written by John Douglas, science writer. Technical background information was provided by Narain Hingorani and Gilbert Addis, Electrical Systems Division.

THE IMPORTANCE OF THYRISTORS TO HVDC

Advanced thyristors to be installed at the LADWP terminal illustrate how solid-state converters are taking on new importance in HVDC applications. The HVDC Pacific Intertie Line represents an important means of reducing the cost of electricity to customers in two regions of the country by interchanging surplus power between them. Such sharing can be balanced seasonally because the Los Angeles area and the Pacific Northwest have complementary periods of surplus power. During the winter and spring, heavy rains in Washington and Oregon permit production of large amounts of relatively inexpensive hydroelectric power. Because of the Intertie, a substantial fraction of the extra power generated can be transmitted economically to Los Angeles. Then, during the dry months of summer and early fall, power from southern California can offset the decline in hydroelectric output in the north.

Because of demand growth in both regions, the Pacific Intertie is being upgraded. Dc voltage will be increased from 400 kV to 500 kV, and the maximum amount of power transmitted will rise from 1580 MW to 2160 MW. An important part of this upgrading may be the replacement of the mercury arc valves with thyristor valves at converter stations. A successful demonstration of the advanced light-fired thyristor valve developed with cost-sharing by EPRI, LADWP, and General Electric could make it a strong contender for use in the conversion.

In addition to the demonstration planned for advanced, light-fired thyristors on the Pacific Intertie, solid-state devices are playing an increasingly important role in HVDC systems around the world. As many nations search for energy resources in remote areas, the need for inexpensive, reliable transmission systems to transport electric power to urban areas is growing. Increasingly, dc lines with converter terminals that use solid-state electronic valves are becoming the technology of choice.

The largest capacity, highest voltage HVDC system in the world is scheduled to go on-line soon in Brazil, taking hydroelectric power from the new Itaipu Dam to São Paulo, some 500 miles away. Not only will a dc link be less expensive, but here there is another reason not to use ac current. The Itaipu project is a joint venture between Brazil and Paraguay, and the dam straddles the Paraná River where it forms their border. Eventually, 12,600 MW will be generated at the dam, making it the world's largest power plant of any kind, with power made evenly available to both countries. Initially, however, Brazil's demand will be much larger and almost all the electricity from the first generators will go to São Paulo.

But Paraguay uses 50-Hz ac current while Brazil uses 60-Hz current, and the first generators will be installed on the Paraguayan side of the dam. Therefore, one of the additional benefits of having a dc link between Itaipu and São Paulo is that it eliminates this frequency mismatch. The HVDC line will have two pairs of poles, one at +600 kV and one at −600 kV. Each pair will normally carry 3150 MW, but if one set of conductors is knocked out of service, the other pair can carry the entire 6300 MW.

Closer to home, another HVDC line is being planned to carry energy from the coal fields of Utah to urban customers in southern California. Called the Intermountain Power Project, this line will have poles at 500 kV. The line is now under construction and is expected to be completed in 1986. □

Garbage disposal is one job; electricity generation is another. If the two can be combined by burning some of the 150 million tons of municipal solid waste (MSW) produced each year, which can be used to generate steam or electricity, so much the better. But the two jobs do not always work together. In the recent past, a number of utilities burned fuel made from their neighbors' MSW in power plant boilers and met formidable technical and institutional difficulties. Today, community and utility interest is shifting toward burning MSW in dedicated boilers and selling the resultant steam or electricity to utilities. Energy can be recovered from refuse, but the circumstances have to be right.

In theory only

Several years ago, the plan of burning refuse-derived fuel (RDF) in utility boilers seemed an obvious solution to a number of community problems. The community would save on rising disposal costs, prolong the life of existing landfills, and avoid the difficulties of siting new landfills—all without having to build incineration facilities. Steel and other recyclables could even be retrieved from the refuse and sold at a profit. While the community's garbage disposal problems were being solved, the utility would continue to generate electricity as usual, or so the theory went.

But as utilities and communities have come to realize through experience, burning RDF in utility boilers can generate not only electricity but problems of its own. Since the early 1970s, RDF has been tried as a utility fuel, and the results have been mixed. Several projects have succeeded, but others have run into trouble. The trouble, as Charles McGowin, project manager in charge of MSW research in EPRI's Coal Combustion Systems Division, points out, was both technical and institutional. Burning RDF in utility boilers may appear to be a good way to dispose of garbage, but it is not necessarily a good way to generate electricity.

To fully comprehend the difficulty of burning RDF in utility boilers, refuse-to-energy burning technologies must first be understood. Four primary methods for turning MSW into energy are at or near commercial availability. Raw MSW may be burned in a dedicated boiler, and the resultant steam or electricity sold to the utility. Coarse, wet RDF (MSW that has been shredded after the recyclables have been removed) may also be burned in a dedicated boiler and the steam or electricity product sold. (Dedicated RDF boilers can use either stoker-firing or fluidized-bed combustion.) Higher-quality RDF may be cofired with coal or oil in power plant boilers. Or the gas produced by waste decomposition at landfills may be collected and burned as a fuel. (Advanced technologies under development include gasification, pyrolysis, and anaerobic digestion.)

All four primary approaches have been tried, but because large amounts of capital are required to build dedicated MSW or RDF boilers and because gas reclama-

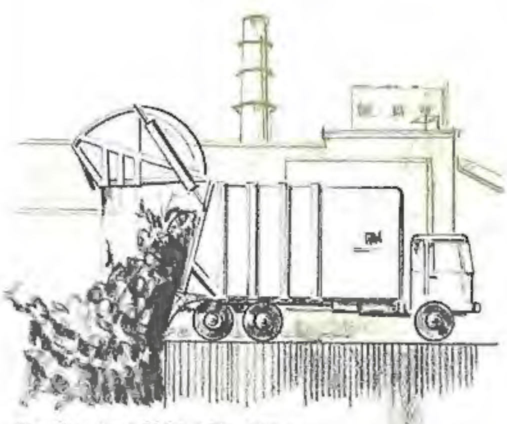
Megawatts From Municipal Waste

Over the past 10 years, a number of utilities have cooperated with their communities by burning refuse with coal or oil in power plant boilers. Some of these projects succeeded, but others ran into sticky technical and institutional difficulties. Now there's a new trend: communities or other agencies burn MSW or RDF in dedicated boilers and sell the resultant steam or electricity to utilities or other energy users.

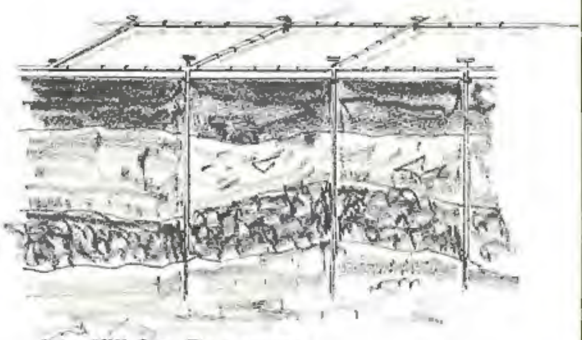
FOUR ROUTES TO ENERGY RECOVERY

RDF Cofiring
Refuse-derived fuel (RDF) can be cofired with coal or fuel oil in utility power plant boilers, but cofiring can lead to reliability problems. Utilities also lack a real economic incentive to cofire.

Dedicated RDF Facility
RDF can also be burned in dedicated incineration facilities, and the steam or electricity product sold. The RDF boilers may be either stoker-fired or fluidized-bed-fired.



Dedicated MSW Facility
Municipal solid waste (MSW) can be mass-burned in incineration facilities dedicated to that purpose. The resultant steam can be sold for use in industrial processes, district heating, or electricity generation; or electricity can be generated and sold directly to customers.



Landfill Gas Recovery
The gases produced as MSW decomposes in landfills can be collected and piped to gas customers. Other, more-advanced MSW-to-energy technologies under development include gasification, pyrolysis, and anaerobic digestion.

tion projects do not solve landfill problems, most utility MSW experience in the past 10 years has been in cofiring RDF with coal or oil in retrofitted power plant boilers. As eager communities saw it, it was only logical that the efficient coal and oil boilers in power plants could burn small quantities (10–20% of total heat input) of RDF without much difficulty. Utilities, willing to cooperate with their neighbors, agreed to lend their boilers for MSW disposal, and since 1970 eight utilities in the United States have cofired RDF in their power plant boilers. Three of these utilities are still burning RDF; three more utilities have plans to start cofiring as well.

In many situations, the problems of burning RDF in utility boilers quickly became apparent. "A little solid waste and a lot of coal seemed to make good engineering sense," says Shelton Ehrlich, manager of EPRI's Fluidized-Bed Combustion and Alternative Fuels Program, "but that little bit of solid waste carried a lot of bad substances with it into the boiler." The organic combustible wastes in RDF, such as paper and wood, mingle with the inorganic incombustible wastes, such as glass and metal. When RDF was fired in the soaring temperatures of power plant boilers designed exclusively for coal or fuel oil, the noncombustibles melted into slag that fouled boiler tubes. Plastic compounds gave off chlorine and hydrogen chloride gases, which increased corrosion of boiler parts. Some combustibles, such as wood chunks and shoe heels, were too large to burn completely in the brief seconds that they fell through the boiler. Their full Btu value was squandered, and when they reached the bottom of the boiler, they obstructed the bottom-ash removal system. Not only were there problems in the boiler, but RDF's contents also created problems in the stack. The plant's ash-handling and air pollution control equipment, designed for the ash and pollutants that coal and oil produce, could be overloaded by the large amounts of particulates produced by burning RDF.

In short, what seemed like a good way to dispose of MSW ended up jeopardizing the efficiency, reliability, and availability that power plant operators had labored to achieve with conventional fuels. Utilities with RDF programs worked hard to solve these technical difficulties, with such groups as EPRI, DOE, and EPA providing technical backup in the effort, and answers to many of the problems were found. For example, utilities discovered that hinged dump grates could be installed at the bottom of suspension-fired boilers to catch unburned RDF. The grates would permit ignited material to burn for a longer residence time, and the grates were periodically opened to allow consumed material to fall to the ash removal system below. In addition, better RDF processing, including trommel and disk screening, could remove more glass, metal, and ash, even if it did increase the cost of the RDF processing and reduce the RDF's Btu yield.

These technical solutions worked. In Ames, Iowa, for example, where a city-owned power plant was converted to RDF cofiring with pulverized coal in the mid 1970s, the addition of bottom dump grates solved the problem of unburned material falling to the bottom of the boiler, according to McGowin. Bottom dump grates were subsequently included in a new pulverized-coal unit at Ames, which successfully cofired RDF with coal this past year. Ames also installed rotary disk screens at its publicly owned RDF processing facility and was able to reduce RDF ash content from 21% to 10%, which, in turn, reduced boiler slagging. In another example, in 1979 dump grates were installed in two of Madison [Wisconsin] Gas & Electric Co.'s coal boilers, which were cofiring RDF processed by a municipally owned resource recovery plant. The results were also a success.

While individual utilities were devising better ways to burn RDF in their boilers, EPRI was also working on some solutions. EPRI's MSW program, begun in 1975 to monitor the developing MSW-to-electricity technologies, concentrated on assessing the impact of RDF cofiring in power plant boilers. In 1981 EPRI sketched out preliminary guidelines for cofiring RDF in these boilers, including necessary modifications for boilers and ash-handling systems. EPRI and Argonne National Laboratory are now cosponsoring a project to prepare detailed guidelines for cofiring RDF in utility boilers. The project will review utility experience with RDF cofiring; develop RDF specifications and recommend flowsheets for RDF preparation; and develop design and operating guidelines for RDF handling, storage, and firing in utility boilers. These guidelines will be adapted for different combinations of boiler and primary fuel types—for example, cyclone, wall-fired, and tangentially fired boilers designed for coal or fuel oil. The results will appear in a handbook, which is expected to be available to utilities in 1984.

Nontechnical questions

Although utilities are overcoming the technical problems of burning RDF as a fuel in utility boilers, there are also some difficult institutional problems involved with cofiring RDF. One of these is the lack of incentive for a utility to participate in an MSW project, other than to provide a community service. State utility regulatory commissions do not permit a utility to derive a profit from using RDF, according to McGowin, so if the RDF is cheaper than coal or oil, no part of the savings can be retained by the utility, despite the fact that RDF cofiring is a more complicated operation than firing conventional fuel. And in many cases, the utility is not permitted to change its cost of power generation to reflect the increase in boiler operation and maintenance costs and the decrease in plant output when RDF is burned. "A utility will get a return on its investment in retrofitting boilers, but it will not get anything for the increased risks to its power plant," explains McGowin.

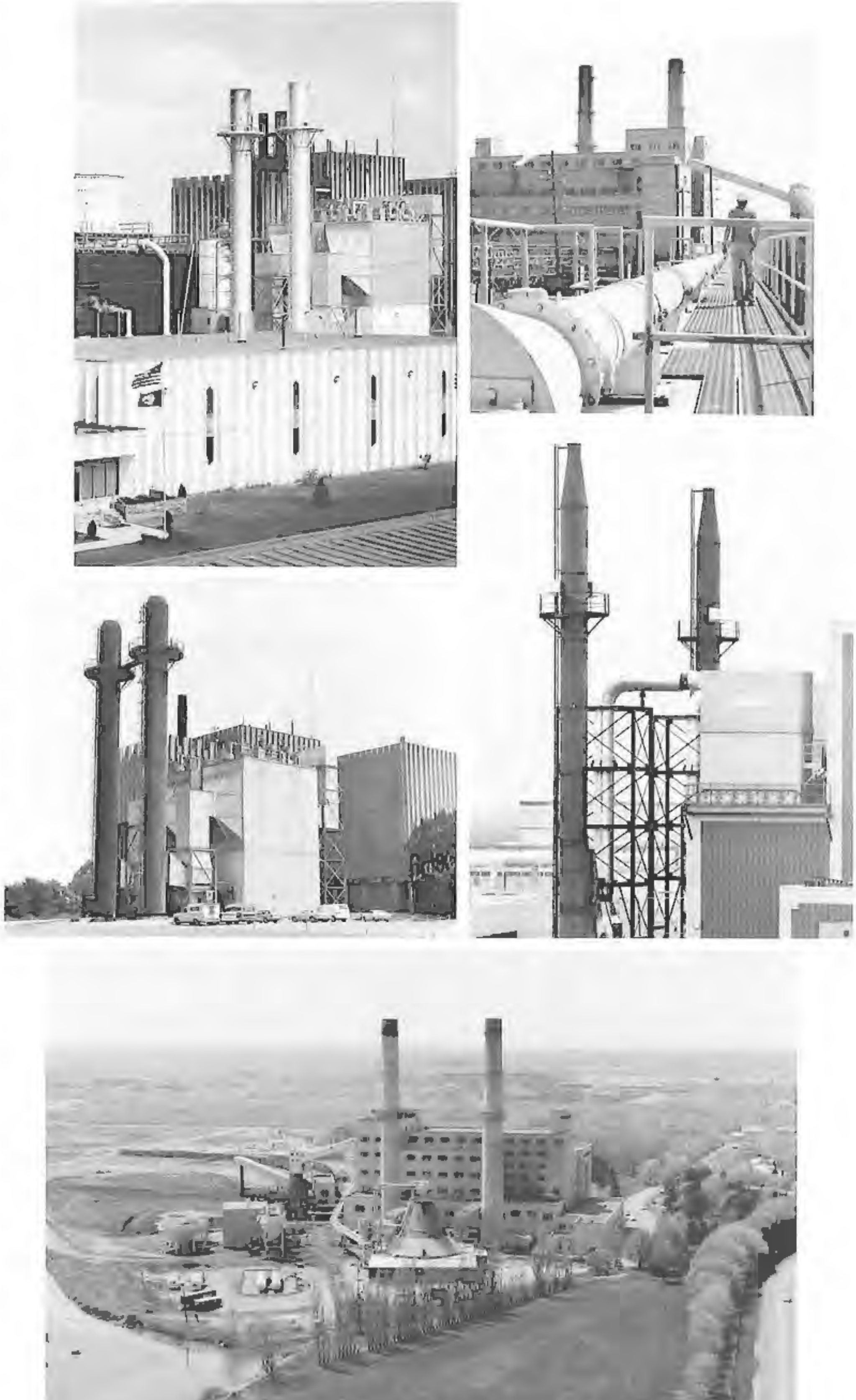
Utilities that cofire RDF may also be exposing themselves to economic dispatch penalties. Utilities dispatch their power plants in the most economic way possible, using lower-cost, more-efficient baseload plants to meet constant electricity demand and higher-cost, less-efficient units to meet intermediate and peak electricity demand. But a boiler that is cofiring RDF must be operated regularly, or the RDF will start to accumulate in receiving or storage areas. By continuing to use the boiler when it would be more efficient to shut it down, the utility may suffer an economic dispatch penalty.

Given the technical and institutional difficulties in cofiring RDF for power generation, a utility that is willing to cooperate with its community's recovery efforts must try to minimize the risks it faces by sharing them with other partners in the project. Typically, utilities require some guarantees on RDF quality and quantity before they will agree to participate in an MSW project. Some utilities have developed specifications for such characteristics as Btu, ash, and water content. These specifications can help ensure getting a fuel that will satisfy at least the minimum requirements for efficient, economical combustion in the utility's boilers. Utilities may specify a contract period of perhaps 20 years to ensure that they will receive enough RDF to justify any boiler or emissions control modifications that have to be made in their power plants. Utilities may also reserve the right to not accept fuel, or they may require a test period of perhaps a year before they sign a long-term contract for RDF.

Risks can also be minimized by asking the MSW processor to pay for any boiler modifications or to require that any expenses the utility incurs for using RDF as a fuel be deducted from the fuel price. This could include such costs as more frequent corrosion inspections, more frequent replacements of conveyor parts, and increased bookkeeping.

Another way

Partly as a result of the risks and uncertainties of RDF cofiring, communities considering energy recovery from MSW



There are dozens of MSW-to-energy recovery programs across the country, from RDF cofiring in Ames, Iowa, and Rochester, New York, to dedicated MSW-burning boilers in Nashville and Gallatin, Tennessee, to landfill gas recovery in Mountain View, California.

have shifted their attention to building dedicated boilers that burn only MSW or RDF and produce steam and/or electricity to sell for district heating, industrial process heat, or electricity generation. This approach is especially attractive to utilities because the purchase of steam or electricity generated at dedicated MSW- or RDF-fired facilities is a simpler arrangement; requires no additional utility fuel handling, fuel storage, or waste disposal; and does not affect the reliability of existing power plants as cofiring does.

Dedicated facilities are also attractive to communities, although for other reasons. A dedicated facility can be built wherever a community's MSW can support it; the community does not have to depend on a local utility having an appropriate power plant boiler for RDF cofiring. A dedicated refuse-burning plant that cogenerates steam and electricity for sale to a range of customers may also be able to secure higher energy recovery—and higher revenues—than if it only sold RDF to a utility. And depending on the outcome of a case now pending before the U.S. Supreme Court, communities may ultimately receive a higher price for electricity than they would for RDF fuel. Under the provisions of the Public Utility Regulatory Policies Act of 1978, which govern the purchase of electricity from refuse-fired cogeneration facilities, public utilities are required to purchase cogenerated electricity at their avoided generation cost. If the refuse-fired generation replaces costly oil-fired generation, the community may receive a higher price than it would if it merely sold RDF to a utility.

Many communities are now considering building dedicated facilities to burn their refuse and generate steam and electricity, according to McGowin, and so more and more utilities are considering buying MSW-generated steam or electricity. Dedicated mass-burning, MSW-fired boilers are operating at Braintree and Saugus, Massachusetts; Harrisburg, Pennsylvania; Chicago, Illinois; Nashville, Tennessee; Norfolk, Virginia; and Waukesha, Wisconsin. Dedicated RDF-fired boilers have been built in Niagara Falls and Hempstead, New York; Akron, Ohio; and Miami, Florida. Most of the steam produced by these plants at this time goes for district heating or industrial process heat, but several of these projects include the sale of steam or electricity to electric utilities, according to McGowin.

The boilers used in dedicated facilities are so-called waterwall boilers, whose walls are lined with water tubing. MSW mass-burning facilities usually convey the fuel into the boiler on moving grates, where it burns without additional fossil fuel. Dedicated RDF boilers usually use semisuspension firing. An extra boiler is sometimes built in both MSW and RDF facilities to increase plant reliability and offset increased maintenance.

Because MSW and RDF contain so many slagging and corrosive elements, dedicated boilers cannot be fired at too high a temperature. The resultant steam is of a lower temperature and pressure than that which conventional utility power plants use to run their turbines; also, steam cannot travel far without losing its heat and pressure. So the utility that buys steam from a dedicated facility will have to build low-temperature, low-pressure turbines at or near the site of the dedicated facility in order to generate electricity. Low-grade steam might also be used to preheat the water going into conventional utility boilers.

Because many more utilities are expected to consider buying steam or electricity generated from MSW or RDF at dedicated facilities, EPRI has mounted a research effort in this area. A new project will document the feasibility, design, economics, and operating experience of dedicated MSW-fired steam and electricity cogeneration facilities planned and operating in Nashville and Gallatin, Tennessee, respectively. The city of Nashville is considering two options: expand the existing Nashville Thermal Transfer Corp. facility or build a new facility to increase refuse disposal capacity. In Gallatin, Tennessee, Sumner County's small cogeneration facility has been operating since early 1982. Both plants sell steam to industrial customers and cogenerated electricity to TVA. The case histories that this study will provide can be referred to by communities planning similar facilities.

Toward a mutual solution

The decision to tie in with a community resource recovery project—be it burning RDF as fuel or buying steam or electricity generated from MSW or RDF—is one that every utility must make for itself. "Utilities can't go into MSW with their eyes closed," emphasizes McGowin. The utility's present generation system, fuel costs, local politics and landfill situation, and many other factors must all be taken into account. Utilities are generally willing to accommodate neighboring communities in their MSW ventures, but because utilities are a business, they must work within the technical and institutional boundaries imposed on them. Only a careful assessment of the situation and study of the MSW experiences that have gone before can tell if the community's disposal problems can be solved without risking utility efficiency, economy, and reliability to do it.

Further reading

Seminar Proceedings: Municipal Solid Waste as a Utility Fuel. Seminar held May 13, 1982, Miami Beach, Florida. EPRI CS-2723.

Cofiring of Refuse Derived Fuel and Coal at Oak Creek, Vols. 1 and 2. Final reports for RP898-1 prepared by Combustion Engineering, Inc., August 1981 and October 1982. CS-1983.

Technology Assessment: Municipal Solid Waste as a Utility Fuel. Final report for RP1255-3 prepared by Ebasco Services, Inc., May 1982. CS-2409.

C. R. McGowin. "Municipal Solid Waste: A Utility Fuel?" *NCRR Bulletin*, Vol. 11, No. 4 (December 1981), pp. 101–108.

Nadine Lihach. "New Fuels for Old." *EPRI Journal*, Vol. 6, No. 3 (April 1981), pp. 6–12.

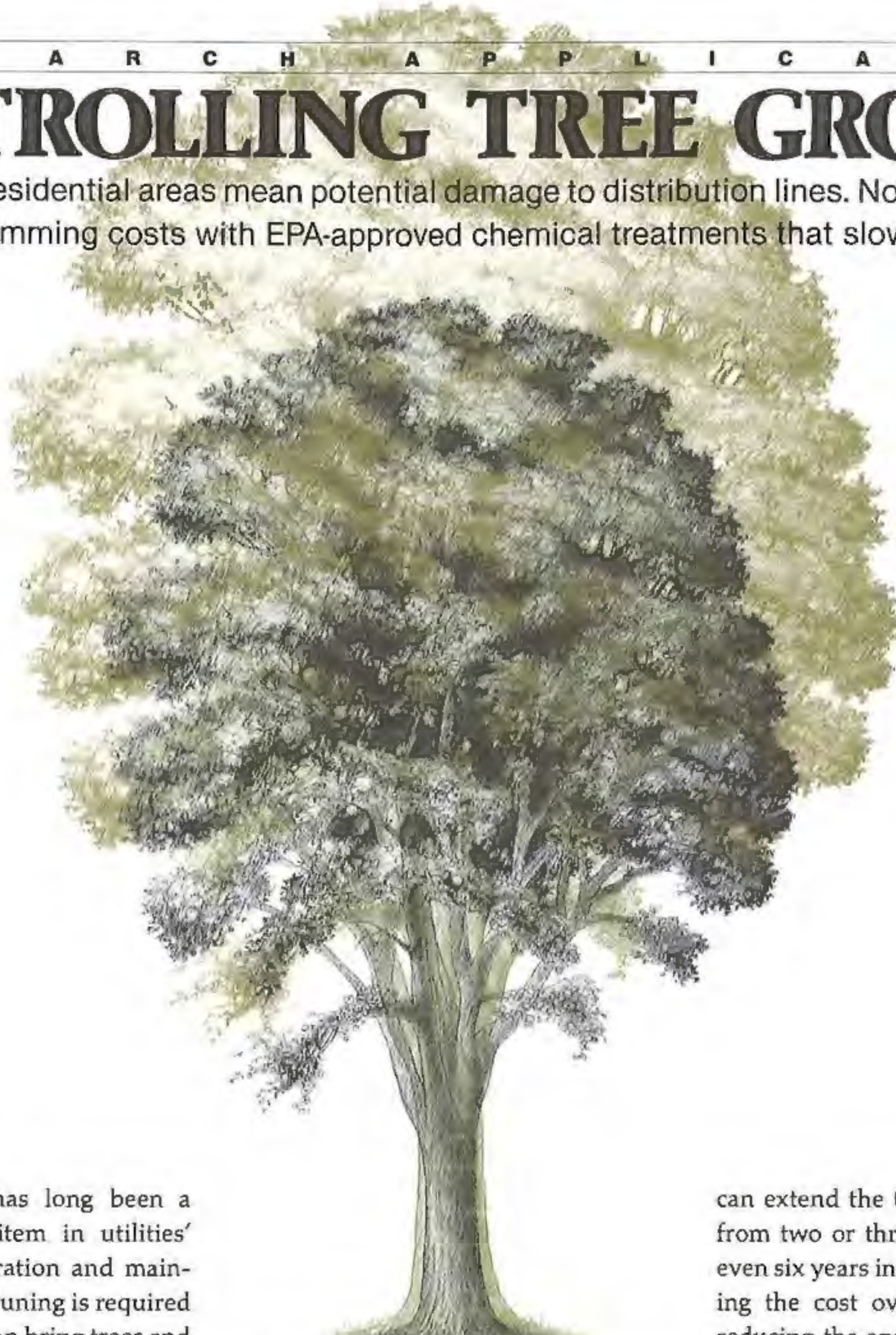
Seminar Proceedings: Municipal Solid Waste as a Utility Fuel. Seminar held January 9–11, 1980, Ft. Lauderdale, Florida. EPRI WS-79-225.

"Municipal Solid Waste—Problem or Opportunity?" *EPRI Journal*, Vol. 2, No. 9 (November 1977), pp. 6–13.

This article was written by Nadine Lihach. Technical background information was provided by Charles McGowin, Coal Combustion Systems Division.

CONTROLLING TREE GROWTH

Tree branches in residential areas mean potential damage to distribution lines. Now utilities can save on tree-trimming costs with EPA-approved chemical treatments that slow regrowth.



Trimming trees has long been a major expense item in utilities' distribution operation and maintenance budgets. The pruning is required because storms or age can bring trees and flying branches down across power lines, necessitating costly and hazardous repairs. Even without catastrophic forces, branches and foliage that grow up around overhead electric distribution lines can interrupt service if they contact a line.

California's Pacific Gas and Electric Co., with some 3,700,000 trees that bother its lines, demonstrates the scope of the problem. To keep the growth under control, crews must trim a third of those trees one year, another third the second year, and the rest the third year—then repeat the cycle. The maintenance is a continual, every-workday, year-round operation. Further, at from $25 to $30 a tree, trimming is not inexpensive. The best estimates show that the U.S. utility industry spends more than $500 million every year on trimming operations.

Electric utilities now have a cost-reducing alternative to expensive tree-trimming operations: EPA has approved chemicals that retard tree growth. The chemical retardants, although they do not eliminate the need to trim, slow the growth of sprouts and reduce the number that appear after pruning. The process can extend the time between trimmings from two or three years to four, five, or even six years in some cases, thus spreading the cost over a longer period and reducing the annual expense to a utility. The chemicals can be applied with a tree trunk injection system at a cost of only $2–$3 per tree.

Ten years ago, when EPRI originated its tree growth retardant work, the objectives were to screen plant growth regulators, determine and document their effectiveness, and develop a safe, efficient, and economical application method (EL-1112). Because most of the troublesome trees are in public view, either on private property or along urban streets, ecology and esthetics were also important considerations.

EPRI's part in the research program

has now been successfully completed (EL-2569). The most significant research results are the development of a portable, air-powered injection system for applying the chemicals and the achievement of EPA approval for two growth retardant chemicals: dikegulac (Atrinal) and maleic hydrazide (Royal Slo-Gro). Out of the approximately one dozen chemicals screened as potential growth retardants, these two were the most consistently effective over a wide range of tree species. Field tests with dikegulac and maleic hydrazide were conducted on 14 species in 12 states and 17 cities, and at appropriate concentrations, they controlled sprout regrowth in most species without causing toxicity to the trees.

EPA approval is in the form of supplemental registration labels for the chemicals that specify their application as growth retardants for particular tree species. Twelve species are now on the EPA-approved labels for chemical injection, with six appearing on labels for both dikegulac and maleic hydrazide: sycamore, London plane tree, bigleaf maple, silver maple, eucalyptus (*Eucalyptus* spp.), and cottonwood. The Atrinal label additionally includes shamel ash, hackberry, water oak, Norway and red maples, and *Eucalyptus sideroxylon*.

Pressure injection is the application method of choice for tree growth retardants. The system avoids the disadvantage of chemicals drifting in the air, and utilities that have worked with EPRI on the project report environmental complaints are practically nonexistent. However, this method is not universally optimal; utilities have found that a combination of application methods is sometimes necessary. For example, injection is not effective on conifers, although bark banding is. Spraying may be the most efficient method for trees in nearly inaccessible areas or for trees growing thickly as a screen or windbreak, where individual treatment is extremely difficult.

When injection is used, tree size dictates details of the procedure. For trees that are 6–16 inches in diameter at breast height, three injection holes, each smaller in diameter than a pencil, are drilled in the tree trunk, equally spaced around the trunk's circumference. Trees larger than 16 inches require six injection holes. The holes are drilled in the zone between the root flare and about 40 inches above the ground; they penetrate horizontally, about 2 inches into the tree. Injection of the chemical into this outer sapwood, which takes it up quickly into the tree, is crucial for effective results.

Dosage and time of application are also important to success of the growth retardant. The correct dosage varies from species to species and has been established at a level that is effective without inducing discoloration or other damage. The dosage also varies according to environmental conditions, with different levels necessary for a very dry or a very wet year. The best time for application is between budbreak and three-quarter leaf development. However, because crews cannot get around to all the trees requiring attention in the three-week optimal period, some trees are trimmed and treated (with an adjusted dosage) during winter dormancy or even after budbreak. Reinjection, like retrimming, is necessary and generally done at the time of pruning. Experiments on reinjection showed renewed growth control without a damaging accumulation of the chemical retardant.

Many utilities aided EPRI in its tree retardant research by providing test sites and evaluation of chemicals: Florida Power Corp., Georgia Power Co., Northeast Utilities, Northern States Power Co., Ohio Edison Co., Pacific Gas and Electric Co., Pennsylvania Electric Co., Philadelphia Electric Co., Portland General Electric Co., The Potomac Edison Co., Texas Electric Service Co., and Union Electric Co. According to Robert Tackaberry, project manager in EPRI's Electrical Systems Division, these utilities are using the retardants and injection system as a regular part of their operation and maintenance programs and are continuing some experimentation. Trial plots on additional tree species are a part of this research; results are reported to chemical companies to enable them to add new species to the labels.

The prospect for continued research and wider application is exciting, but the best news is in the here and now. With two growth retardant chemicals approved and commercially available, utilities now have an effective alternative to frequent trimming that can save them money. ■

Growth retardants are usually pressure-injected into the tree's outer sapwood through holes that are less than a quarter-inch in diameter. The correct dosage varies with the species being treated.

This article was written by Rosalyn O. Barry. Technical information was provided by Robert Tackaberry, Electrical Systems Division.

Promoting Federal Efficiency

Dexter Peach of the General Accounting Office talks about current energy trends and the GAO's strategy for effective oversight of federal energy programs.

Established as an independent, nonpartisan legislative agency by the Budget and Accounting Act of 1921, GAO was formed to help Congress provide an economically and effectively run federal government. It fulfills its mission by overseeing, auditing, and evaluating the programs, activities, and financial operations of all federal agencies and departments—from the Department of Health and Human Services to the Department of Energy (DOE).

To probe into the energy issues reviewed by GAO, the *EPRI Journal*'s Washington correspondent recently interviewed J. Dexter Peach, director of GAO's Resources, Community, and Economic Development Division. Peach was director of the Energy and Minerals Division prior to its recent merger with the Community and Economic Development Division. Involved in GAO activities since 1960, Peach recently received the Comptroller General's Award for his leadership in GAO's energy work and his efforts to effect positive changes in the nation's energy and minerals policies and activities. Peach offers a broad perspective on current energy trends as a result of many years' experience in energy issues and through the preparation of planning documents and energy analyses for GAO.

Is energy a principal area of concern at GAO?

Energy is certainly one of the major issues under our authority. GAO's energy operations are organized to deal with specific fuel sources, such as nuclear, fossil, and renewable resources, as well as other areas that bear heavily on the future of energy—conservation and policy planning, for example. We maintain specific responsibility for audit and liaison with the DOE, the Nuclear Regulatory Commission (NRC), energy-related portions of the Department of the Interior, and the Synthetic Fuels Corp. (SFC).

What guidelines does GAO use in choosing areas of concern for near-term review?

We recently completed development of what we term the strategic plan covering the next 24 to 31 months. Through this plan we try to identify important and emerging energy issues and those energy programs where our audits can have the most impact. We also try to anticipate the issues that will have the highest congressional interest and identify areas for which a broad summary report within the next two years would be timely.

What is the significance of the strategic plan when much of GAO's work is by congressional request?

GAO's reviews do involve both work initiated under its basic legislative statutes and that done at the request of Congress. If our plan is effective, we will have correctly anticipated much of the congres-

Peach

sional interest and will be one step ahead of the game. Of course, we run into problems and must make adjustments if congressional interest does not coincide with our own planning. For that reason, we try to assess areas that will require congressional decisions and provide the background and evaluation audits to assist congressional staff in the decision-making process. For example, we know Congress will have to make a decision in the 1984 timeframe on future funding for SFC. In this regard, we will examine the issues that would be of concern to Congress, including SFC's process for selecting and funding projects and its overall effect on development of the synthetic fuels industry.

The Pacific Northwest Power Act, which has been in place for about four years, is another piece of legislation that we have targeted specifically for evaluation. We think it would be helpful for Congress if we put together a report card of sorts on how the act has worked to meet electricity needs and use within that region. GAO will evaluate each major component of the act in terms of regional electricity supply and demand planning and the effectiveness with which conservation and renewable resources are being applied. We will also look at how the act has worked to maintain fisheries and ecological systems.

Would you highlight some of the targeted issues of specific interest to the electric utility industry?

Our strategic plan targets 14 areas for the near future. For some of these, individual studies will be pulled together to form the basis for a summary report; in other areas, work will cover various aspects of issues but not necessarily result in a summary report. Those topics for which a summary report is planned and which have relevance to the utility industry are the adequacy of federal energy emergency preparedness, the understanding of electricity supply and demand and the selected federal role, and the effectiveness of nuclear power regulation in the aftermath of Three Mile Island (TMI). Other areas on which we will focus within the next two or three years involve the future viability of nuclear power as a domestic energy source, the implications of the changing federal role in energy R&D, and the impact and continued need for federal financial incentives for conservation and renewable energy.

You mentioned that one GAO target area concerns the effect of TMI on the utility industry. What does that study involve?

We are mainly interested in analyzing what has happened in nuclear power regulation since TMI. Five years after NRC was created, Congress requested that GAO provide an overview of how effectively NRC carries out its responsibilities. Interestingly enough, GAO's overview came out at the same time NRC was being scrutinized so carefully because of the TMI event. I think the question of how well NRC is dealing with TMI's aftermath, including how well it is responding to the questions about nuclear power that TMI raised, is worth revisiting. In addition, we want to see how effectively NRC has implemented the recommendations made by GAO and others.

This review of the aftereffects of TMI differs from a more general look at the nuclear power industry. For the TMI question, we have plans to produce a summary report. In the general area of nuclear power, however, we will examine questions that pertain to what needs to be done to make nuclear power a viable option. Because there are no orders pending for new nuclear plants, this is a good time to take a hard look at the issues and options. Even if the outlook improves and orders pick up again, many of the problems that have been with us for years would still require resolution.

Does GAO plan to address the administration's philosophy on the federal and private sector roles in energy R&D?

The administration's energy R&D policy begs the question of what is meant by long-term, high-risk R&D. There are also unanswered questions about the private sector's role in the research, development, and demonstration of certain technologies. A demonstration facility of reasonable size requires a heavy investment, coupled with a great deal of risk. When the private sector commits to a capital investment of that magnitude, it wants some kind of assurance of a good return on its investment. Because many promising energy technologies have both technical risks and risks associated with our uncertain energy future, they are not likely to meet the investment tests of the private market. In essence, certain technologies just fall through the cracks. GAO will be looking into the roles and effects of federal and private funding in greater depth within the next two or three years.

What can the private sector do to minimize the loss of certain promising technologies?

To a degree, organizations like EPRI can fill the void in energy R&D that now exists, particularly in the electric utility area. The amount of money that utilities can spend on R&D is constrained by the regulatory environment in which they operate. So private research organizations like EPRI offer an opportunity to pool relatively limited resources and undertake larger projects that can benefit all utilities. Still, given the environment in which utilities operate, there are obvious limits to what an EPRI can do.

What promising alternative technologies are on the horizon?

I think fluidized-bed combustion technology will continue to push ahead. It is clearly a cleaner way of using coal, and the concerns raised today about excess capacity make smaller plants, such as those used in fluidized-bed technology, additionally attractive. There should be a good market for that size plant around the world—particularly in the smaller developing countries where there isn't the need for a thousand-megawatt plant.

Speaking of excess capacity, is there congressional concern over future electricity needs?

I think this particular issue is going to be a very important one in Congress, and its members will need comprehensive and objective assessments to help them put supply and demand questions into perspective.

After the 1973 oil embargo, projections for electricity demand continued to increase. At the same time, we at GAO were grappling with the effect this drastic change in oil prices would have on electricity demand. Experience has shown that the inflated price of oil, coupled with an unhealthy economy, led to a substantial decrease in electricity demand. Due in part to consumers' reactions to increased fuel prices and implementation of conservation measures, demand did not reach the predicted levels.

The difficulty arises when trying to correctly anticipate supply and demand levels. The possibility exists that we could be just as wrong now in projecting very low growth rates as we were when we projected a continued high growth rate after the oil embargo.

Would you elaborate on GAO's plans in the electricity supply and demand area?

We plan to survey data and information compiled by diversified sources, such as the Tennessee Valley Authority, the electric reliability councils, and research organizations like EPRI. Although there have been numerous studies in this area, each involves different assumptions and so each results in a different projection. After evaluating these estimates, it should become easier to pinpoint the sensitive areas that provide the basis for differences in supply and demand projections. Then we will address how improved utility planning and operations can minimize the costs and risk of future demand and supply imbalances.

The ultimate objective of our study is to inform Congress of ways the nation can achieve an adequate and cost-effective power supply. In an industry that anticipates tremendous capital expenditure requirements by the year 2000, even the smallest improvement in operations can translate into hundreds of millions of dollars in savings. And ultimately these savings affect the ratepayer.

Do you feel that the recent oil glut has diminished congressional interest in energy, placing it on the back burner relative to other issues?

Considering the number of congressional requests for GAO energy-related studies, energy certainly does not seem to be on the back burner. As a matter of fact, energy has been repeatedly one of the highest congressional interest areas at GAO. To provide a yardstick, only about 35–40% of GAO's overall work is generated by congressional request. Last year, however, about 65–70% of our work in the Energy and Minerals Division was from congressional inquiries. This clearly indicates to me continued congressional interest in energy.

But in terms of what has happened with certain technologies that were being pursued, the recent oil glut has stifled progress. I have been involved in energy in Washington since about 1973—the time of the first Arab embargo—and I've noticed a roller coaster effect. Every time a shortfall occurs in the world's oil supply, there is an incredible amount of sudden interest in new technologies. When we return to a sense of normalcy because of an improved oil supply situation, the urgency to develop technologies for future needs virtually disappears. In the last two years, we have lost a lot of momentum, and I wonder if the situation were to tighten up again, how well prepared we would be.

What role will energy conservation play in the future?

Conservation by all counts continues to be our cheapest energy "source." But it can only substitute for other sources up to a point and must be considered in the correct perspective. It is still not a new source of energy from the standpoint of being able to replace existing plants on their retirement. We need to continue to seek additional energy supplies.

Finally, one area of current interest is talk of DOE dismantlement. Is GAO providing Congress with an evaluation of this prospect?

Yes, we have completed two reports that address this question. The first, "Analysis of Federal Energy Roles and Structure," was done in January 1982. In this study, we tried to define the options available to Congress in structuring an energy organization. We discussed the implications of dismantling DOE, continuing it as is, or going to some form of partial dismantlement.

In August we released a report called "Analysis of Energy Reorganization Savings Estimates and Plans," which examined the savings estimates and plans for the administration's proposal. As you may recall, the administration indicated that such a reorganization would realize considerable dollar savings. We found, however, that there was little support to back that savings claim. In fact, in the short run, such a reorganization could well cost money.

As the proposal is still before Congress, GAO has been asked to look at a number of specific questions about the proposal's implications, such as how international energy activities would be carried out under the proposed change and the effects of the reorganization on nuclear power and nuclear weapons research. Similar questions on the transfer of programs to the Departments of Agriculture and Commerce are also of concern. I think this study, together with the other two, should provide Congress with substantive background information to assist in making a policy decision on how to best organize the complex world of energy policy and R&D programs. ■

This article was written by Ellie Hollander, Washington Office.

Advanced Battery to Begin Tests

Zinc chloride prototype initiates evaluations of advanced batteries at EPRI's BEST Facility.

Long-term testing of a zinc chloride advanced battery design will begin in mid 1983 at the Battery Energy Storage Test (BEST) Facility in Hillsborough Township, New Jersey. Installation of 10 modules that will form a 500-kWh battery is planned under a $3 million contract between DOE and Energy Development Associates (EDA), a subsidiary of Gulf+Western Industries, Inc.

Data to be gathered in the tests will determine whether the zinc chloride battery is compatible with a utility grid and can be operated and maintained by utility personnel. Cost, safety, and factors affecting reliability, including response to electric surges, will also be studied. This work will help identify improvements needed for the development of a commercial design.

EPRI and EDA are each posting 25% of the cost of installing the battery modules, with DOE funding the remaining 50%. EPRI, a participant in zinc chloride technology development since 1974, is pledging continued R&D support for the project into 1984. Its financial support, including the next phase, now amounts to $10 million; EDA and DOE support amounts to $15 million and $11 million, respectively.

David Douglas, EPRI project manager for zinc chloride batteries for utility application, said testing of the modules is scheduled to run for a year but may be extended. "Over the last eight months we have had zinc chloride batteries that operated reliably and continuously, an event in itself," added Douglas.

The BEST Facility, jointly owned by DOE, EPRI, and Public Service Electric and Gas Co. (New Jersey), will be continuing its research on advanced battery concepts with several other projects. A lead-acid battery specifically designed for utility load leveling is tentatively scheduled for placement at the facility in 1984, according to Douglas. Plans call for the next generation of battery technology (either zinc bromide or sodium-sulfur) to be installed for testing in 1985.

EV Interest Remains Strong

Utility and auto industry representatives met last fall at TVA to discuss the latest developments in electric vehicle research. The meeting, organized by EPRI with the assistance of the Electric Vehicle Council, attracted 110 participants, including 52 representatives of 38 electric utilities. Jerry Mader, EPRI program manager for electric transportation and host of the meeting, said the response to the workshop indicated a strong interest in advancing the electric vehicle.

Those attending heard projections that electric vehicles could be commercially competitive by the end of this decade. The key to this prospect, according to Mader, lies in battery improvements now under development. S. David Freeman, past chairman of TVA and a former EPRI board member, added that the utility industry will have to be the innovator in developing electric vehicles.

The workshop's keynote speaker was Peter J. McTague, chairman of Green Mountain Power Corp. and a member of the EPRI board of directors. McTague called the battery-powered car an idea whose time has come: "For the producers and distributors of electricity, the electric car can tailor and reshape the way energy is allocated, make optimal use of our generating capacity, and reduce foreign oil dependency."

Workshop participants visited TVA's EV Test Facility near Chattanooga and test-drove a number of electric vehicles around the facility's mile-long oval track. Used for road performance and handling tests, the dual-banked track provides different surfaces for testing at 35 and 55 mph, with a maximum grade of 0.6%.

TVA built the EV Test Facility to accommodate the needs of EPRI and others involved in electric vehicle development. The facility includes a chassis dynamometer, battery test laboratory, service bays, and charging equipment. An HP-1000 project computer controls battery testing, supports data acquisition, and stores an extensive electric vehicle data base for comparison purposes. ■

Human Factors Work Appraised

Results of EPRI's research on human factors were recently evaluated as part of an independent study funded by the Nuclear Regulatory Commission (NRC). Carried out by a team from the Human Factors Society, the study contains recommendations for a 10-year human factors R&D program and concludes that the EPRI program has been successful in meeting the team's evaluation criteria.

The Institute's research goal in this area is to reduce human error, promote plant safety, and improve operational effectiveness. Specific areas covered by the NRC review include control room design and enhancement, maintainability, job performance aids, the disturbance analysis and surveillance system (DASS), the safety parameter display system (SPDS), communications, annunciator warning systems, cool suit development, physical anthropometric criteria, CRT displays, and training.

The results of EPRI's human factors research are being used by utilities and architect-engineers as well as by the Institute of Nuclear Power Operations. During 1982 about 40 utilities received INPO workshop instruction in applying EPRI-developed methods of control room enhancement. ■

Gas-Insulated Cable Research Continues

Testing of a single-phase, sulfur hexafluoride (SF_6) insulated transmission system is progressing well at EPRI's Waltz Mill test facility near Pittsburgh, Pennsylvania. The project is a cooperative effort between DOE, which developed the equipment, and EPRI, which installed it and now directs the testing.

When the tests are completed this spring, the prototype will be shipped to the Bonneville Power Administration test site in Oregon, where the system will combine additional SF_6 components and a 1200-kV transmission line. The second test series at BPA may last from three to five years and provide advanced knowledge of an SF_6-insulated system.

Ralph Samm, EPRI program manager, said the tests conducted to date indicate that the equipment will operate successfully. John Shimshock, the EPRI project manager at Waltz Mill, said he foresees no difficulties for the remaining test period.

Rigid compressed-gas-insulated cable offers the potential for transmitting large quantities of power underground and is particularly attractive where space requirements are critical.

The prototype, capable of transmitting 5000 A at 1200 kV, consists of a 50 × 14-ft (15 × 4-m) cable loop, an air-to-SF_6 entrance bushing to connect to overhead lines, transformers to circulate the current, an SF_6-insulated surge arrester, and an instrument section. The system is subjected to continuous as well as cyclic loads at a maximum of 10% over rated voltage. Evaluations include mechanical performance, particularly location of hot spots and response to cyclic expansion and contraction. Researchers are also looking into the effect of simulated operation on the SF_6 gas, such as the possible generation of contaminants within the system. ■

CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

JANUARY

30–February 1
ASME–EPRI Annual Radwaste Management Workshop
Charlotte, North Carolina
Contact: Michael Naughton (415) 855-2775

FEBRUARY

1–3
Workshop: Hydro Operation and Maintenance
San Francisco, California
Contact: Charles Sullivan (415) 855-8948

8–9
Sampling and Analysis of Utility Pollutants
Los Angeles, California
Contact: Winston Chow (415) 855-2868

15–17
VIPRE–RETRAN Meeting
Charlotte, North Carolina
Contact: Joseph Naser (415) 855-2107

16–18
2d Symposium on Integrated Environmental Controls for Coal-Fired Plants
Denver, Colorado
Contact: Edward Cichanowicz
(415) 855-2374

16–18
1983 International Daylighting Conference
Phoenix, Arizona
Contact: Arvo Lannus (415) 855-2398

MARCH

22–24
2d Conference on Fabric Filter Technology
Denver, Colorado
Contact: David Eskinazi (415) 855-2918

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

MHD POWER GENERATION

Since the inception of applied research in magnetohydrodynamics (MHD) in the 1950s, test facilities dedicated to this technology have grown rapidly in number, size, and complexity. Today the largest U.S. MHD research center is DOE's Component Development and Integration Facility (CDIF) in Butte, Montana. Operated by Mountain States Energy, Inc., the center is a 50-MW (th) engineering-scale test facility for MHD topping-cycle components. One of EPRI's major MHD efforts has been to develop a dc-to-ac inverter system for CDIF. The system, designed by Westinghouse Electric Corp., has been installed and is now being tested. Vital technical support regarding interface issues has been provided by Avco Everett Research Laboratory, Inc., the developer of the MHD generator, and by Montana Power Co., the host utility. This cooperative effort by industry and government has led to the first delivery of appreciable MHD power to a utility grid in this country—a significant milestone toward MHD commercialization. This report describes the inverter development effort, as well as a related EPRI project with General Electric Co. on dc power consolidation circuits.

A critical aspect of delivering MHD power to a utility grid is the conversion of the MHD generator's raw dc output into usable ac power. Inverters and converters are available from manufacturers today, but they are not ideal for use with MHD generators. Some of these off-the-shelf devices are relatively unsophisticated, with components that have not been designed for the dc-ac interactions of a totally integrated MHD energy delivery system. They can produce ac electricity warped by harmonics, generate electromagnetic interference, and cause electrical instabilities at both dc and ac interfaces. All this, in turn, can consume useful power and interfere with the proper functioning of utility and customer equipment.

More-advanced equipment—power-conditioning systems (PCSs)—could go beyond rudimentary dc-to-ac conversion and revamp the resultant ac waves into the power required by utilities and their customers. Since the early 1970s, EPRI and DOE have been sponsoring the development of specifications and designs for PCSs of the future. At the same time, as part of an effort to develop design criteria for inverters for large-scale MHD generators, EPRI has specified PCS designs based on conventional, state-of-the-art hardware rather than advanced concepts. This approach was taken to minimize both R&D effort and the cost of installing and testing the PCS equipment at CDIF.

In addition to state-of-the-art inverter hardware testing at CDIF, EPRI is sponsoring an effort to analyze advanced power consolidation circuits—networks for delivering the dc power output of numerous MHD electrode pairs to a single PCS for conversion to 60-Hz ac. Together these activities should lead to more-realistic predictions of the on-line behavior and control requirements of MHD generator-inverter units.

PCS development

In August 1979 EPRI selected Westinghouse to provide PCS equipment to produce 3.5 MW of high-quality 60-Hz ac power when connected to the MHD generator at CDIF (RP642-2). The basic thrust of this effort was to design and construct a PCS for operation as part of a totally integrated MHD energy delivery system. Tests would be conducted to assess PCS interactions with the MHD generator and the utility grid. Also, MHD generator characteristics would be documented in the four PCS automatic control modes (in which dc voltage, current, impedance, or power is held constant).

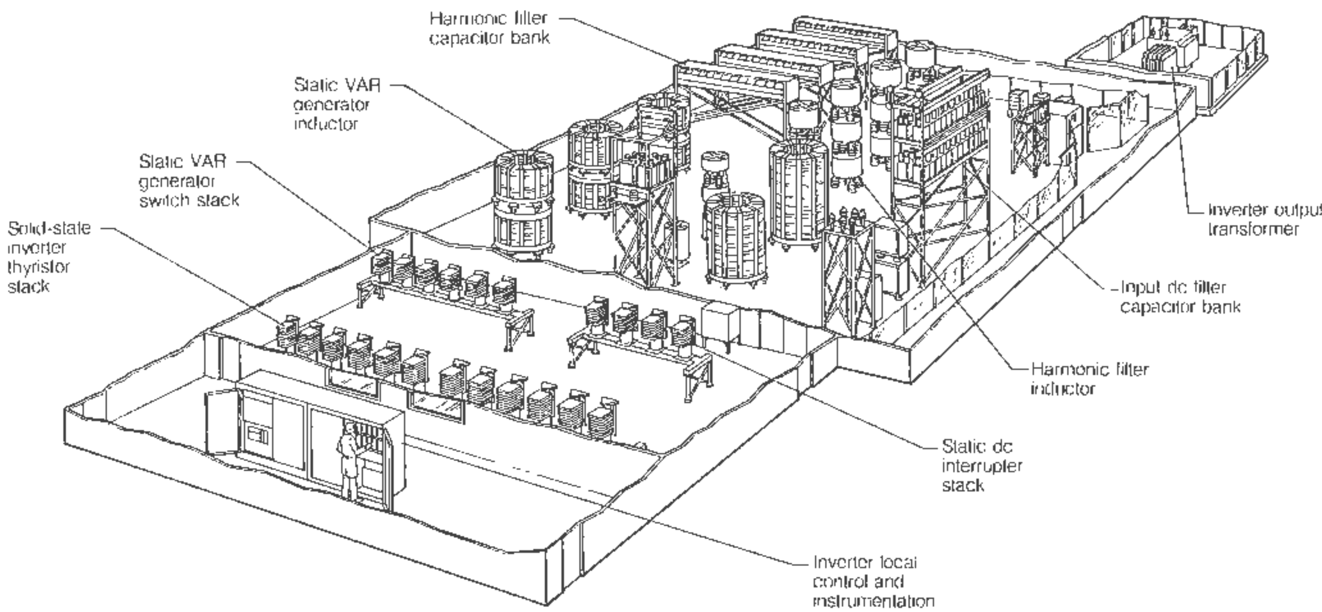
Major tasks of the Westinghouse contract were to define the PCS functional requirements and to produce detailed electric power and control circuit designs with associated instrumentation and diagnostic devices. Additional work involved the development of CDIF support requirements, detailed layout drawings, factory and field checkout procedures, and startup, shutdown, and operational manuals.

In mid 1981 all PCS equipment fabrication and assembly work was completed, and all factory performance testing and procedure demonstrations were successfully accomplished. Each major component or subsystem, such as printed circuit boards and modules, was tested to ensure that it functioned as intended by design. The factory testing did not attempt to simulate interactions with the MHD generator. Rated dc voltage and current inputs were applied to the equipment under test, but not simultaneously because of facility limitations. Procedures, acceptance criteria, and data sheets for documenting the tests were included in the test report.

The PCS equipment was delivered to CDIF in late 1981. Site support documentation was issued for building and utility services design and for PCS equipment installation. The construction and installation work was completed by Mountain States Energy in March 1982. Figure 1 shows the major dc-to-ac conversion components as installed in the MHD inverter building.

On April 22, 1982—following eight weeks of preoperational checkout and startup efforts—the PCS delivered over 400 kW of ac power to the Montana Power Co. grid as the MHD generator supplied approximately 550 kW of dc power to the PCS. The PCS was tested in the voltage control mode at levels up to 4 kV. Startup transients and tests involving the sudden loss of the MHD generator were successfully negotiated. The PCS controlled the MHD generator voltage well as

Figure 1 This power-conditioning system, developed under EPRI contract for DOE's Component Development and Integration Facility, inverts the MHD generator's dc output into usable ac power. Tests of the system at the facility have resulted in the first delivery of appreciable MHD power to a utility grid in this country.



generator output characteristics were modified by programmed changes in the magnetic field and in channel plasma conditions. Data on the generator output characteristics were collected by slowly ramping the PCS dc voltage set-point levels. Preliminary computations of generator performance agreed well with the recorded data. The significance of this test is that for the first time, the inherent stability of a fully integrated MHD power system was demonstrated at 400 kW ac with closed-loop automatic voltage control.

During October 1982 dc power was conditioned to ac power by the PCS in four test firings. The PCS was operated in each of the four control modes (voltage, current, impedance, and power). Figure 2 shows the control levels and four simultaneously observed dc and ac parameters for an extended test. To date, more than 4 MWh of MHD energy have been supplied to the Montana Power Co. substation. A final report detailing the PCS development effort and test results will be issued the first part of this year.

The successful testing of this large-scale inverter at CDIF represents a significant step forward in MHD development. The opportunity now exists to observe the behavior of an MHD generator that is connected to an inverter, as well as the behavior of power as it flows from the inverter into a utility grid. Technical data and insights developed from ongoing integrated system tests can provide the benchmark for the next-generation MHD plant.

Power consolidation circuits

In May 1980 General Electric Co. was chosen by EPRI to initiate development and analysis work on alternative designs for dc power consolidation circuits (RP642-4). The objective of this effort was to provide the preliminary R&D necessary to define an efficient, reliable, and cost-effective consolidation circuit for power collection from either a Faraday or a diagonally loaded MHD channel in baseload operation. While there seems to be no consensus in the industry regarding the integration of consolidation circuits into an MHD system, three general concepts have been advanced (Figure 3); these have served as the basis for the General Electric work.

The major guidelines for the circuit development effort were as follows.

- Electrical isolation must be maintained between neighboring electrodes; that is, the tendency for current to circulate between adjacent electrodes must be inhibited.

- The circuits must be nondissipative; efficiencies should be 95% or higher.

- The circuits must regulate individual electrode current to maintain proper current distribution and thus prevent electric shocks, boundary layer separation, electrode current overloads, and interelectrode overvoltages.

- The circuits must not induce destructive electric transients in either the channel or the PCS.

- The circuit designs must be able to be commercially manufactured, allowing for reasonable extrapolation of state-of-the-art power electronics.

The project plan called for General Electric first to establish the functional requirements of the MHD environment in which the consolidation circuits must operate. With a preliminary specification in hand, the researchers were then to identify, analyze, and rank candidate circuits according to their operating characteristics, efficiency, reliability, cost, and suitability for development. Next, a comparative performance analysis

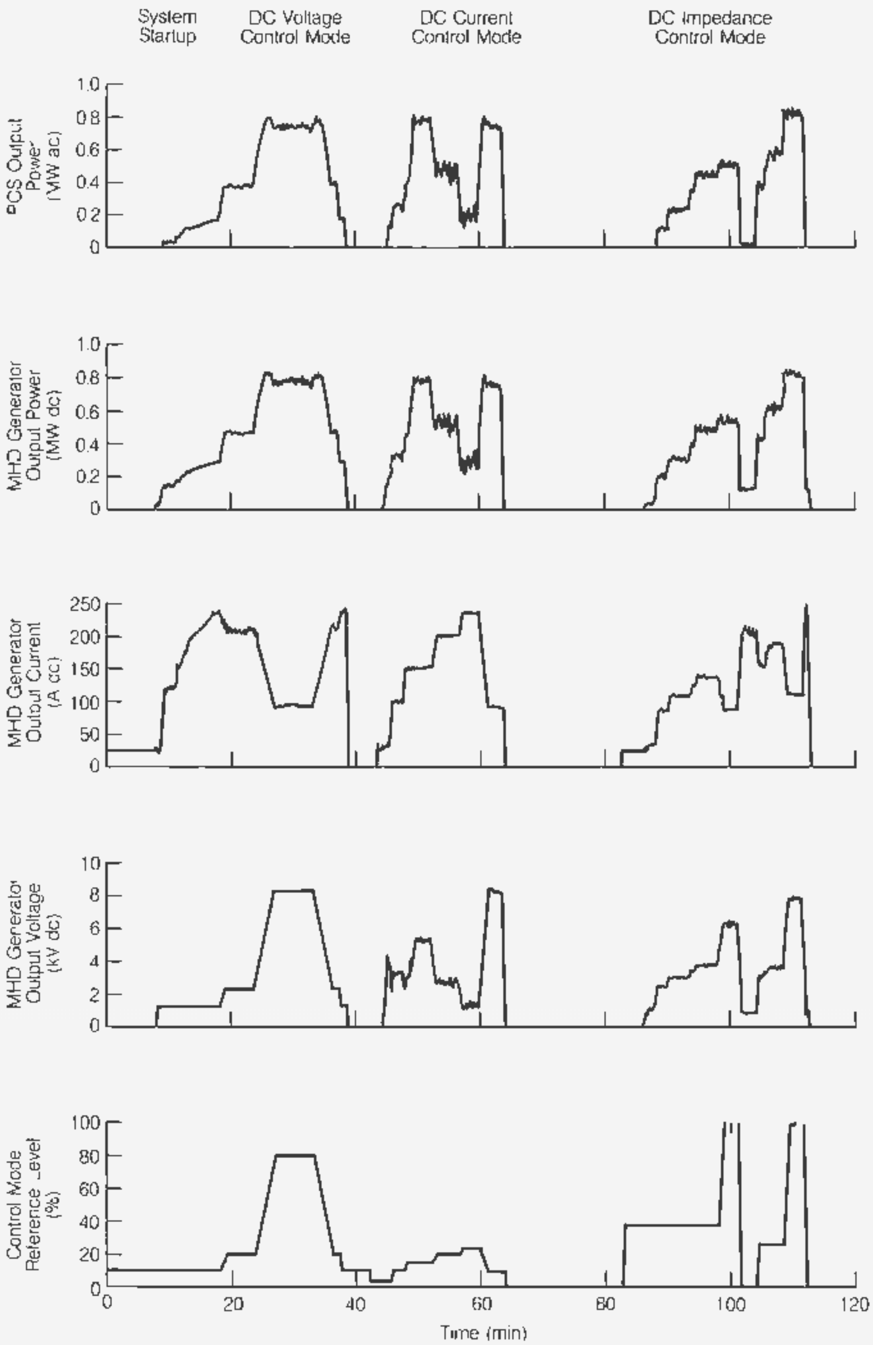


Figure 2 MHD generator dc parameters and PCS ac output power for an extended test in various dc control modes. For each mode the data show the inherent stability and the efficiency of the fully integrated inverter system during closed-loop operation. (The control mode reference level is stated as a percentage of the maximum value attainable for the parameter being controlled.)

was to be conducted, and two candidate systems were to be developed and tested as breadboards in a circuit simulating an MHD channel and the downstream PCS equipment. Finally, the comparative performance analysis for the two systems was to be updated on the basis of the breadboard test results.

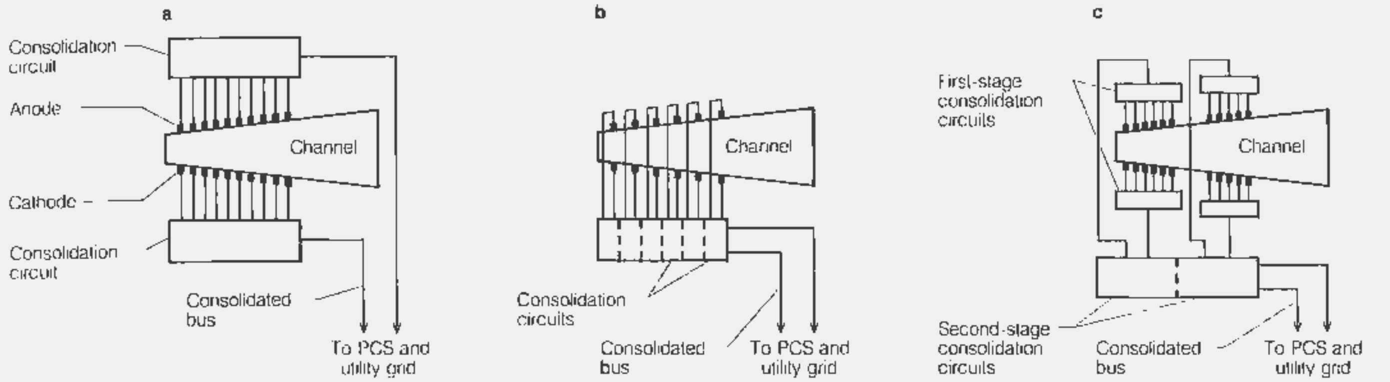
General Electric has completed a preliminary specification for consolidating multiple electric outputs from an MHD generator into one or (at most) a few buses. The proposed specification defines the functional requirements for consolidation systems, while remaining neutral about the kind of technology used to achieve these objectives. Regardless of type, the consolidation scheme must satisfy high efficiency and reliability requirements for all operating modes of the MHD system. In addition, the specification addresses MHD system startup, shutdown, and standby; consolidation circuit input and output parameters; fault conditions; environmental requirements; physical size; and safety.

General Electric emphasizes that the designer of consolidation equipment must maintain an overall system perspective to ensure that both the equipment's interface with the channel and its interface with the utility grid are addressed. Specifically, a successful design must consider (1) all the static and dynamic operating modes and fault modes of a total MHD energy delivery system, and (2) the desired ac power quality, the power factor of operation, and other electric utility interface issues.

The specification is based on MHD designs developed in previous DOE studies. Using two teams, one at General Electric and one at Avco, DOE conducted a series of studies aimed at establishing the actual design of an MHD power plant. The resultant designs are generally similar, and the electrical parameters that form the basis for the specification can be considered representative of an early commercial MHD plant. The specification necessarily reflects the tentativeness of the present state of MHD power plant design.

To analyze candidate consolidation circuits more vigorously, an equivalent circuit for an MHD generator was derived. The approach to evolving a realistic assessment vehicle entailed two steps: devising a network of impedances and voltage sources that would resemble a channel and developing an analytic model of the channel with which to evaluate this network. A two-dimensional mathematical model was developed and was used to determine channel performance under fault conditions. These results were

Figure 3 General consolidation concepts are illustrated for an MHD channel segment. In the first configuration (a), voltages between adjacent anodes and between adjacent cathodes are consolidated; in the second (b), voltages between anodes and cathodes (transverse voltages) are consolidated. In the third configuration (c), a hybrid of the other two, voltages between adjacent electrodes are consolidated in the first stage and transverse voltages are consolidated in the second.



then compared with the fault performance of proposed equivalent circuit networks. After several modifications, a network of impedances and sources was devised that compared quite well with the analytic model of the channel.

Equipped with the preliminary consolidation circuit specification and an equivalent circuit for an MHD channel electrode pair, General Electric identified and evaluated four candidate consolidation schemes. The operating principles of each scheme and the basic analyses for various boundary conditions will be detailed in the project's final report (forthcoming); some insights for ranking the candidate schemes are discussed below.

One scheme involves a high-frequency dc/dc converter system. Although such a system could be used for consolidation of the electrode pairs of a Faraday connection, all power would have to pass through these converters and also through a main inverter into the ac network, resulting in low efficiency. Also, because it has no provision for reverse power flow, this scheme would not be applicable to buck/boost operation. Another disadvantage is that the cost of thyristors for high-frequency inverter service is high and will remain considerably higher than the cost of units for 60-Hz service. Further, the voltage rating of inverter-grade thyristors is relatively low, making it necessary to connect thyristors in series, which would not be entirely satisfactory for this type of unit. Although the small size of the inductive components and capacitors at high frequencies make this system attractive, the overall disadvantages argued against the selection of this scheme for development and testing as a physical model.

The second scheme involves an autotransformer system. An analysis of this scheme indicated that there were undesirable waveform disturbances in electrode current and voltage at the moment of commutation. After a basic analysis of the commutation process, several methods for mitigating the distortions were evaluated. It was decided that although the autotransformer system would be capable of acceptable operation in consolidation systems, considerable work is necessary at the hardware level to develop a practical system. Thus, this scheme was not selected for physical model development.

The third scheme, a capacitor switching system, proposes that for two pairs of adjacent electrodes, one capacitor be connected between the anodes and another between the cathodes. A means of switching, for instance a thyristor, is provided for reversing the current; thus current can flow directly into either of the two like electrodes, through the capacitor, and into the other electrode. The system uses relatively inexpensive components and is theoretically controllable. But the problem of a suitable control circuit to regulate current against electrode disturbances has not been solved and may require considerable effort. Although this system shows some promise, it was not selected for further development.

The fourth scheme is called a buck/boost system. This concept suggests that by inserting a low-voltage, line-commutated converter on each side of an electrode—between the electrode and a common dc bus—the Hall (axial) voltages may be counteracted and electrode currents consolidated. The concept of transferring some power from one electrode pair to another in order to allow consolidation of the output currents has been described in the literature. The possibility of using a current-fed, line-commutated converter in a three-phase bridge form was originally suggested by General Electric.

On the basis of several factors, including the state of the art, the availability and cost of components, and the reliability and flexibility of available control techniques, General Electric considers the line-commutated buck/boost consolidation system to be the most desirable of the four schemes investigated.

Only the initial analysis of candidate consolidation circuits has been completed to date; plans for circuit hardware fabrication and further analysis are being formulated. *Project Manager: Ralph Ferraro*

MATERIALS FOR SYNGAS COOLERS

In an integrated coal gasification–combined-cycle power plant, high efficiency is combined with the potential for greatly reduced sulfur and particulate emissions. Entrained slagging gasifiers are considered advantageous for these plants because they produce only gaseous pollutants, mainly hydrogen sulfide, which can be removed from the synthesis gas (syngas) by available industrial processes. However, the syngas produced in entrained slagging gasifiers is at a high temperature, and to achieve high efficiency, its sensible heat must be recovered before removing the particulates and the gaseous *pollutants at room temperature. Process developers currently propose to achieve this through radiation and convection coolers, in which steam is generated for electricity production. These syngas coolers are large pressure vessels that as currently designed represent 10–15% of the total capital investment for an oxygen-blown coal gasification–combined-cycle facility. Under RP1654-5 with Lockheed Missiles & Space Co., Inc., EPRI has sponsored the testing of several metals, alloys, and coatings in a simulated gasifier environment to find materials suitable for service in syngas coolers.*

Syngas cooler design and operation

Heat exchangers for entrained slagging coal gasifiers are similar to those used in conventional pulverized-coal plants. Generally the hot raw syngas, which leaves the gasifier at 1100–1400°C, is first cooled by radiation in a large, empty chamber similar in function to the furnace of a pulverized-coal-fired boiler. Here the temperature of the raw syngas is reduced rapidly by radiation to the inner wall of the cooler, which consists of water-cooled tubes. The heat thus absorbed is used to produce steam by evaporating part of the circulating cooling water. The partially cooled raw syngas then enters a convection cooler, which closely resembles the superheater, reheater, and economizer sections of a pulverized-coal-fired boiler. Here additional heat is removed from the syngas by convective cooling. The gas leaves the convection cooler at a temperature slightly above its dew point and is then further cooled by quenching with water in a particulate scrubber.

In general, heat exchangers for entrained slagging gasifiers are more complex than those in pulverized-coal boilers. Because most gasification processes operate at high pressures (500–1000 psi; 5440–6890 kPa), the heat exchangers must be enclosed in pressure vessels. This limits access and may complicate repair and cleaning operations during shutdowns. Soot-blowing systems for high-pressure operation are also more complex and must be specially designed.

The most fundamental difference in the operating conditions of syngas coolers and pulverized-coal boilers is the gas composition. The raw syngas from an entrained slagging gasifier is very reducing and contains a considerable amount of hydrogen sulfide. Experience in the petrochemical industry indicates that commonly used boiler steels sulfidize under such conditions. This can result in very high corrosion rates, especially at superheater and reheater temperatures. For this reason the syngas coolers of first-generation gasifiers are generally designed for evaporator and economizer duty only, in which the metal temperature is kept below 500°C.

Corrosion experiments

Because of the lack of design data on the corrosion resistance of metals, alloys, and coatings in raw syngas, EPRI initiated a preliminary laboratory study to determine the relative corrosion resistance of various commercially available materials (RP1654-5). In this study, alloys and coatings were exposed for up to 3000 hours in flowing syngas with a hydrogen sulfide concentration of 0.6%. The exposure was isothermal and at atmospheric pressure.

It was found that iron sulfide scales formed on carbon steel and on the two low-alloy steels tested—T-11 (1.25% chromium, 0.5% molybdenum) and T-22 (2.25% chromium, 1% molybdenum). Figure 4 shows the corrosion rates as extrapolated to one year for the carbon and T-11 steels. Surface recession rates were excessive at 400–500°C and marginal at 300°C, especially if a 20-year life is required.

Several ferritic and austenitic stainless steels were tested. Results indicate that increasing the chromium content of ferritic alloys to 18–26% greatly increases their corrosion resistance. The surface recession rate of these alloys was low up to 500°C, even though a fully protective chromium oxide scale did not form. Austenitic stainless steels with 18–25% chromium and 11–32% nickel behaved very similarly to ferritic stainless steels with the same chromium content. Table 1 gives corrosion penetration depths for various ferritic and austenitic steels. Most of the alloys have a slight tendency to pitting, but generally the pits were small and did not increase much in size when the exposure

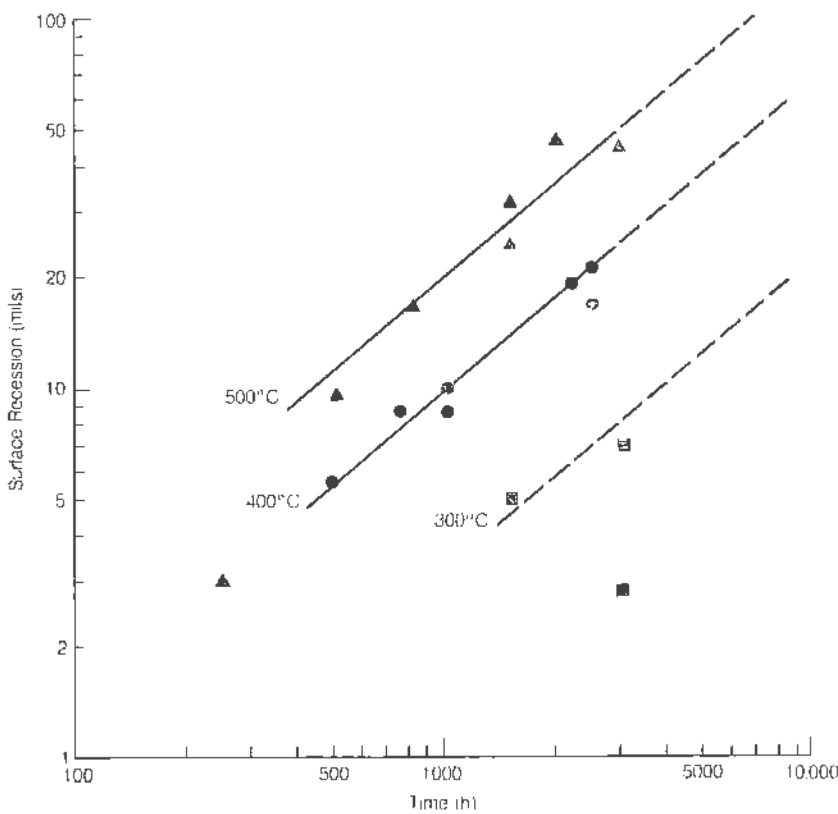


Figure 4 Surface recession rates for 1020 carbon steel (black symbols) and T-11 low-alloy steel (color symbols) in a simulated gasifier atmosphere at 300–500°C. Linear extrapolation of the test results indicates the following annual recession rates: 20 mils/yr at 300°C, 60 mils/yr at 400°C, and 120 mils/yr at 500°C.

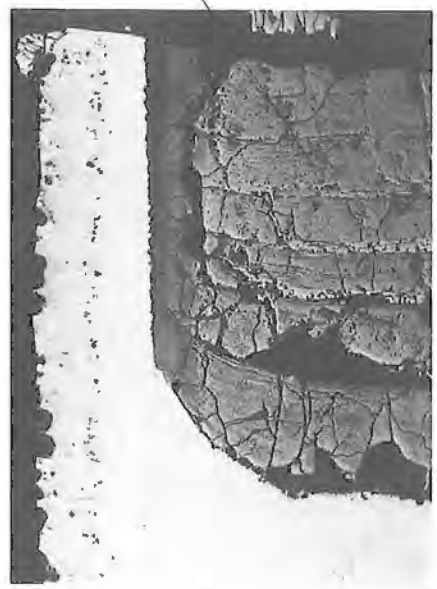
Table 1
CORROSION OF FERRITIC AND AUSTENITIC STAINLESS STEELS IN RAW SYNGAS

Alloy	Time (h)	Maximum Corrosion Depth (mil) 300°C	400°C	500°C
Ferritic stainless steel				
Type 439	1018	—	0.75*	—
	1515	0.15	—	0.25
Austenitic stainless steel				
Type 304†	1538	0.075	0.30	0.25, 1.2*
Type 347	1018	—	0.15	—
	1515	0.15	—	0.3, 1.3*
	2538	—	—	0.30
	3038	0.10	0.10	—
Type 309	1018	—	0.10	—
	1515	—	—	0.15
Type 310	1515	—	—	0.10
Alloy 800	1018	—	0.10	—
	1515	—	0.31	0.36
	2538	—	0.25	—
	3048	0.05	—	0.45

*Pitted.

†Preoxidized for 100 hours in air at 500°C.

Figure 5 This 1.2-mm-wide section of a coated T-11 steel pipe shows the corrosion resistance of an aluminized coating in a simulated gasifier atmosphere (1515 hours at 500°C). Along the cut edge of the sample (top), the exposed steel substrate has been severely corroded and thick iron sulfide scales have formed. In contrast, little attack is evident on the aluminized surface coating at the left.



time was increased from 1500 to 3000 hours.

Coatings high in aluminum or chromium that are applied by pack cementation show promising corrosion resistance when properly applied. Aluminized coatings were found to be fully protective up to 500°C; no measurable sulfide scale formation was noted on the coatings' surface (Figure 5). Some cracking of the aluminized layer did occur, however, and it appeared to increase as the chromium content of the substrate increased. Also, aluminized coatings containing less than 15% aluminum in the area near the substrate have partially corroded away on this inner side. Thus a minimum aluminum content of 15% is indicated for these coatings. Chromized coatings were generally protective. Chromium carbide tended to precipitate at the grain boundaries, however, which led to selective corrosion along some boundaries.

Plasma-sprayed aluminum coatings were also generally found to be protective. A layer of corrosion products formed at the coating-substrate interface, however, especially at 400 and 500°C. This may lead to premature spalling of the coating, although none was observed in the 3000-hour laboratory test.

In summary, the preliminary corrosion data from these tests (which are reported in detail in AP-2518) indicate that common low-alloy boiler steels may not be corrosion-resistant enough for use as heat exchanger tubing in syngas coolers. However, the performance of a number of commercially available alloys and coatings, especially high-chromium stainless steels (such as type 310) and aluminized coatings, was promising.

The corrosion data obtained in this project cannot be used directly as design data for syngas cooler materials because the laboratory tests did not fully simulate syngas cooler conditions. The following additional factors may affect corrosion rates in actual syngas cooler service.

▫ Pressure effects. Some data from the petrochemical industry indicate that the corrosion rate depends on the hydrogen sulfide partial pressure.

▫ Effects of minor gas impurities. Chlorides, which are present in raw syngas at levels of 200–600 ppm, are known to influence corrosion rates adversely. Ammonia may reduce corrosion rates.

▫ Effects of thermal gradients. Heat exchanger elements will be cooled on the inside while being exposed to the hot syngas on the outside. This may increase high-temperature corrosion rates.

▫ Corrosion during downtime. Sulfide scales may oxidize to sulfuric or polythionic acids in moist air during shutdowns and cause acid corrosion.

These factors are presently under investigation in a follow-up project with Lockheed (RP2048-1). Materials are also being exposed in available pilot plants to obtain in-service corrosion data for comparison. *Technical Area Manager: Wate T. Bakker*

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

MHD POWER GENERATION

Since the inception of applied research in magnetohydrodynamics (MHD) in the 1950s, test facilities dedicated to this technology have grown rapidly in number, size, and complexity. Today the largest U.S. MHD research center is DOE's Component Development and Integration Facility (CDIF) in Butte, Montana. Operated by Mountain States Energy, Inc., the center is a 50-MW (th) engineering-scale test facility for MHD topping-cycle components. One of EPRI's major MHD efforts has been to develop a dc-to-ac inverter system for CDIF. The system, designed by Westinghouse Electric Corp., has been installed and is now being tested. Vital technical support regarding interface issues has been provided by Avco Everett Research Laboratory, Inc., the developer of the MHD generator, and by Montana Power Co., the host utility. This cooperative effort by industry and government has led to the first delivery of appreciable MHD power to a utility grid in this country—a significant milestone toward MHD commercialization. This report describes the inverter development effort, as well as a related EPRI project with General Electric Co. on dc power consolidation circuits.

A critical aspect of delivering MHD power to a utility grid is the conversion of the MHD generator's raw dc output into usable ac power. Inverters and converters are available from manufacturers today, but they are not ideal for use with MHD generators. Some of these off-the-shelf devices are relatively unsophisticated, with components that have not been designed for the dc-ac interactions of a totally integrated MHD energy delivery system. They can produce ac electricity warped by harmonics, generate electromagnetic interference, and cause electrical instabilities at both dc and ac interfaces. All this, in turn, can consume useful power and interfere with the proper functioning of utility and customer equipment.

More-advanced equipment—power-conditioning systems (PCSs)—could go beyond rudimentary dc-to-ac conversion and revamp the resultant ac waves into the power required by utilities and their customers. Since the early 1970s, EPRI and DOE have been sponsoring the development of specifications and designs for PCSs of the future. At the same time, as part of an effort to develop design criteria for inverters for large-scale MHD generators, EPRI has specified PCS designs based on conventional, state-of-the-art hardware rather than advanced concepts. This approach was taken to minimize both R&D effort and the cost of installing and testing the PCS equipment at CDIF.

In addition to state-of-the-art inverter hardware testing at CDIF, EPRI is sponsoring an effort to analyze advanced power consolidation circuits—networks for delivering the dc power output of numerous MHD electrode pairs to a single PCS for conversion to 60-Hz ac. Together these activities should lead to more-realistic predictions of the on-line behavior and control requirements of MHD generator-inverter units.

PCS development

In August 1979 EPRI selected Westinghouse to provide PCS equipment to produce 3.5 MW of high-quality 60-Hz ac power when connected to the MHD generator at CDIF (RP642-2). The basic thrust of this effort was to design and construct a PCS for operation as part of a totally integrated MHD energy delivery system. Tests would be conducted to assess PCS interactions with the MHD generator and the utility grid. Also, MHD generator characteristics would be documented in the four PCS automatic control modes (in which dc voltage, current, impedance, or power is held constant).

Major tasks of the Westinghouse contract were to define the PCS functional requirements and to produce detailed electric power and control circuit designs with associated instrumentation and diagnostic devices. Additional work involved the development of CDIF support requirements, detailed layout drawings, factory and field checkout procedures, and startup, shutdown, and operational manuals.

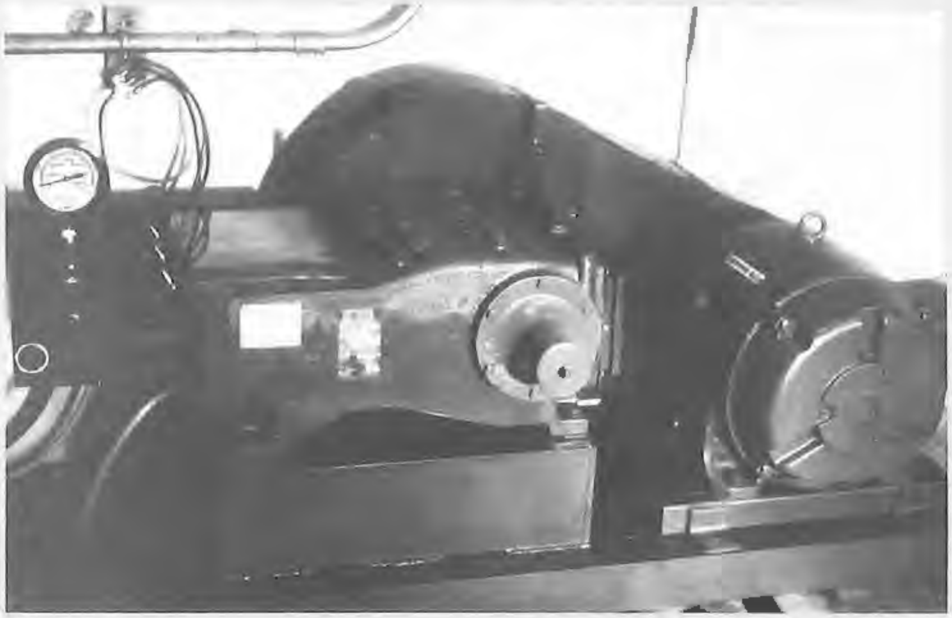
In mid 1981 all PCS equipment fabrication and assembly work was completed, and all factory performance testing and procedure demonstrations were successfully accomplished. Each major component or subsystem, such as printed circuit boards and modules, was tested to ensure that it functioned as intended by design. The factory testing did not attempt to simulate interactions with the MHD generator. Rated dc voltage and current inputs were applied to the equipment under test, but not simultaneously because of facility limitations. Procedures, acceptance criteria, and data sheets for documenting the tests were included in the test report.

The PCS equipment was delivered to CDIF in late 1981. Site support documentation was issued for building and utility services design and for PCS equipment installation. The construction and installation work was completed by Mountain States Energy in March 1982. Figure 1 shows the major dc-to-ac conversion components as installed in the MHD inverter building.

On April 22, 1982—following eight weeks of preoperational checkout and startup efforts—the PCS delivered over 400 kW of ac power to the Montana Power Co. grid as the MHD generator supplied approximately 550 kW of dc power to the PCS. The PCS was tested in the voltage control mode at levels up to 4 kV. Startup transients and tests involving the sudden loss of the MHD generator were successfully negotiated. The PCS controlled the MHD generator voltage well as

Figure 1 A five-orifice, sapphire-jeweled nozzle for cutting concrete.

Figure 2 To supply the pressurized water to the test nozzles in the laboratory, a triplex pump (left) is driven by a 60-hp electric motor (right). A field unit will use a diesel motor.



motor and triplex pressure pump will be used to obtain a 10–20 ksi (69–138 MPa) water supply (Figure 2). Approximately 15 different nozzle orifice configurations will be evaluated, and the most effective design will be mounted on a small handcart assembly (resembling a rotary lawn mower).

Cutting tests performed to date have proved that 14-ksi (96.5-MPa) water with No. 36 grit-size garnet abrasive can cut concrete and the embedded hard-quartz aggregate. Flow of the garnet abrasive, which costs about $0.12/lb ($0.05/kg), has been limited to approximately 1.2 lb/min (9.07 g/s). This can reduce operating costs to less than $1000/mi ($1600/km). *Project Manager: Thomas J. Rodenbaugh*

DISTRIBUTION

Lightning research

The protection of electric distribution systems against the effects of lightning is widely practiced by utilities, but perfect protection has not been achieved. On some systems, 40–50% of all customer service interruptions are attributable to the effects of lightning, and millions of dollars are spent annually to repair lines and replace equipment damaged by lightning. Only the West Coast utilities are largely spared the need to provide extensive surge protection for their distribution systems.

It is not for lack of research effort that protective practices and equipment are imperfect. The manufacturers of surge protective and insulation equipment in particular have made substantial contributions to advance the state of the art of surge protective devices and general protective practices and insulation coordination. This contribution has been supplemented by the efforts of a host of others, including utilities, professional organizations, analytic and consulting engineers, and universities.

The work of so many researchers working independently, however, suffers from a lack of coordination. Goals may be different, and duplication of effort may creep in. Further, up to a few years ago research equipment was limited to very expensive devices intended primarily for use in a laboratory. Even with suitable field-serviceable equipment, some lightning research projects are simply too large to be funded by a single company.

In 1980 EPRI's Distribution Advisory Task Force approved a project to prepare a comprehensive and coordinated plan for the future research needed to improve utility lightning protective practices (RP1980). In this project, the contractor, Ebasco Services, Inc., reviewed both past and current research that was useful to utility operations. Utilities were surveyed to determine what they thought was needed and a number of projects with specific objectives evolved. These were outlined in broad terms so cost estimates could be made and a performance schedule prepared.

Projects identified in the plan fall into the following categories.

- Measurement of ground flash density and lightning stroke characteristics
- Determination and analysis of the dynamic behavior of lightning on distribution lines
- Development of improved surge protective practices

Each category consists of one or more projects, and the performance schedule is based on a logical arrangement, as well as on the assumption of optimal funding availability. In actuality, performance will be governed by the availability of funds and priorities as perceived by the advisory task force. Further, applicable research completed by others may make it unnecessary to perform some research or may make it necessary to revise the scope of other work.

Two areas of lightning-related research are now being pursued; the first is to determine ground flash density, and the second, to complete development of a lightning transient recorder.

The objective of the ground flash density project is to prepare a statistically adequate map of lightning strikes to earth to replace the inadequate thunderstorm-day method of estimating stroke density. This is a large project, one of those that an individual researcher in all likelihood could not perform on a nationwide basis. The State University of New York at Albany, however, has a network of lightning locators that covers a substantial part of the eastern United States, funded by several federal agencies, a utility, and another university. EPRI will be negotiating with the university to process ground flash density maps of the region. This pilot project will enable the researchers to assess this method of determining flash density and to identify the problems and advantages of extending the network. In addition to ground flash density, data on stroke polarity, multistroke count, and peak field data for each stroke are recorded. Means for deriving peak current from the peak field data are being studied.

In the late 1970s DOE funded the development of a lightning transient recorder and subsequently deployed 30 in the Tampa–St. Petersburg–Sarasota area for field trial. Development of this recorder was a milestone in that it made possible the measurement of surge currents in real life with field-serviceable equipment. EPRI is now updating the design of this recorder with Macrodyne, Inc. (RP2005-1). The recorder will have the same overall capability as the prototype, but as it is being designed and constructed by 1982 state-of-the-art standards, its operational capability and characteristics will be substantially enhanced. Both voltage and current can be recorded.

The recorder can be used in future projects to study lightning characteristics and the dynamic behavior of lightning on distribution lines. It is also the type of research tool that every utility should have. For that reason, every effort is being made to keep it as simple, rugged, reliable, and low in cost as possible. It should be available in early 1984. *Project Manager: Herbert Songster*

Electric meter tampering detectors

Electric watthour meter tampering and energy diversion are topics of such concern today that no discussion is necessary on why a project was undertaken in this area (RP1779). Honeywell Technology Strategy Center is the contractor to develop a device or a technique that will positively ascertain a meter has been tampered with. This project was started June 1982 and is well past the initial phases; the project ends December 1983.

The approach was to identify tampering methods and quantify the usage and economic impact of each. This led to the development of detection strategies that addressed not only the most popular methods but also the more sophisticated methods. (Naturally, a more sophisticated and costly device is needed to detect the more intricate tampering schemes.) Several devices of varying complexity are being evaluated before making a final selection.

The basic requirements for the detector are easy installation on both old and new meters; positive, nonvolatile indication; compatibility with meter operation and accuracy; little or no power necessary; and the same operational environment as meters (including handling).

An important consideration, of course, is the cost. Economic analyses will be performed, and a favorable cost-benefit ratio will be an important factor in the selection of a device for final development.

The selected device will be manufactured, tested, and optimized, after which 100 will be manufactured for installation in meters and for field evaluation. Three kinds of installation environments are anticipated.

▫ High-tampering area. Meters will be monitored regularly.

▫ Employees' homes. Employees will attempt to defeat the detector.

▫ Routine installation. Handling and installation will be evaluated.

Project Manager: Herbert Songster

Distribution fault current study

An analysis of the characteristics of distribution system faults has been completed, and the final report will be available during the second quarter of 1983. During the course of this project, Power Technologies, Inc., performed the following.

▫ Developed, along with Macrodyne, the fault recorder described in the *EPRI Journal*, June 1980, p. 57

▫ Deployed 50 recorders among 13 cooperating utilities

▫ Developed the digital computer programs for analyzing the recorded fault and cold-load pickup data (RP1209)

▫ Made statistical analyses of the characteristics of the currents and voltages associated with faults and cold-load pickup

The cooperating utilities supplied the electrical and physical parameters of the feeders on which the recorders were installed. Where possible, they also supplied information about the circumstances of individual faults. This information allowed Power Technologies to compare such data as calculated and measured fault currents for a number of faults.

In all, over 200 faults were recorded. Many of these were temporary faults, and therefore the circumstances of the faults could not be determined for correlation with the recorded data.

The report basically presents the statistical distribution of fault characteristics. For the cases where it was possible to compare calculated and measured fault current magnitudes, they agreed fairly well. Feeder cold-load pickup was not found to be a problem, because portions of the feeder load generally had been restored from alternative sources before the feeder breaker was closed. It was not possible to study cold-load pickup on feeder sections that had been disconnected by fuse operation because the recorders were installed at feeder heads. *Project Manager: Herbert Songster*

URD cable follower

A large number of distribution cables are buried beneath city sidewalks and backyards and in the landscaped areas behind sidewalks in fully developed subdivisions. Eventually these cables fail and must be replaced. The cost of this replacement is very high because a failed cable must be excavated along its entire length and replaced, and the site restored to its original condition.

The development of a cable-following tool that requires only minimal start- and endpoint excavation, does not disturb the surface between these points, and creates a stable hole would greatly facilitate the cable replacement operation and thus lower its cost (Figure 3). Such a tool would not only provide for more economical cable replacement but would also solve many public relations problems presently associated with cable replacement activities.

High-pressure water jets are now commonly used for many mining, construction, and manufacturing applications, including soil removal at relatively low pressures (5–

Figure 3 Cable follower with activated jets, ready to be loaded onto a cable. The water jets can be reconfigured to the best advantage for the type of soil being penetrated.

10 ksi). With EPRI funding and direction, Flow Industries designed, fabricated, and is testing a prototype water-jet cable-following tool to replace failed cables (RP1287).

The tool being tested is capable of penetrating some soil types (sand, sandy loam, and most loams), using high-pressure water jets to remove the soil surrounding a failed cable. Modifications are expected to enable the tool to penetrate the harder packed clay soils. The tool advances by means of a hydraulic mechanism that grips the cable and advances the tool. The grippers push against the cable and move forward in inchworm fashion. While the first grips the cable, the second moves forward. The second gripper then pushes against the cable, while the first moves forward.

The hole created is sufficiently stable to remain open for a few hours or as long as several days, depending on the soil type and condition. In sandy soil, where the borehole could collapse behind the boring device, stabilizers can be added to the water in the jets, bringing about a chemical reaction with the sand that produces a firm conduitlike surface. When temperatures drop below freezing, the device can continue operating with the addition of certain antifreeze solutions to the water supply.

The power supply for the tool is mounted on a trailer that contains hose reels, hydraulic pumps, and water tanks. A single umbilical hose trails the tool.

To use the follower, a pit is dug at each end of the failed cable. The tool is loaded or fed onto the cable and activated (Figure 4). The cable follower's self-advancing mechanism moves the tool to the other end, where it can be removed. A new cable (or conduit) can be attached to the old cable and drawn into the hole as the old cable is withdrawn. After resplicing or reconnecting the cable, the pit is backfilled and the surface restored.

The tool is about 30 in (76.2 cm) long and weighs 31 lb (14 kg). It can advance in some soil types at 4 ft/min (1.22 m/min), but its average rate is half that. The design penetration distance is 200 ft (61 m), using water pressures up to 7 ksi (47.6 MPa) at flow rates up to 4 gal/min (0.25 mm^3/s). A hydraulic advancing system operates at approximately 1.5 ksi (10.2 MPa) at a flow rate of 2 gal/min (0.13 mm^3/s).

The contractor has tested the cable follower under laboratory conditions; field tests continue and testing at utilities will follow. *Project Manager: T. J. Kendrew*

Improved XLPE cable insulation manufacturing process

High-voltage power cable with cross-linked polyethylene (XLPE) insulation was introduced commercially in the late 1960s, and it is now the predominant type of cable in the electrical industry for primary feeder and distribution circuit wiring. The rapid growth in the use of XLPE-insulated cables can be attributed to their low cost and the simplicity of their installation and maintenance. In addition, XLPE insulation exhibits excellent physical and electrical properties. These cables have largely replaced butyl rubber–insulated, shielded-and-jacketed, and paper-insulated lead-sheathed power cables.

It is recognized that although early performance of XLPE-insulated cables, either directly buried in the ground or installed in ducts, has been excellent, they still exhibit a failure rate that increases with time of service. In contrast to cables insulated with thermoplastic polyethylene, long-term performance has been better; but XLPE systems do not appear to perform as well as anticipated after 10 years of service. This problem has been referred to in earlier *Journal* articles that reviewed other EPRI-sponsored projects in this area (e.g., *EPRI Journal* September 1982, p. 47, and March 1981, p. 45).

One reason for the problem relates to imperfections in the insulation structure, some of which are inherent in current cable manufacturing processes. Accordingly, a project with Cable Technology Laboratories, Inc., was undertaken to develop a method of producing XLPE-insulated cable with fewer inherent imperfections (RP1593).

To understand why this problem is inherent it is necessary to review how these cables are prepared. First, polymer pellets are passed through an extruder, which surrounds the metallic conductor with a concentric layer of insulation. (Concentric layers of carbon-black–filled polymer are also applied between the conductor and its insulation and outside the insulation, employing separate extruders; these components are referred to as semiconducting strand shield and insulation shield layers.) On leaving the extruder, the insulated cables pass through a long tube that induces cross-linking of the polyethylene by using high-pressure steam to decompose a peroxide incorporated in the original pellets. (The decomposed peroxide causes the polyethylene to cross-link.)

The cable is cooled as it passes through a long water trough. It is at this point in the manufacturing process that imperfections are introduced—during cooling, the external part of the cable core solidifies relatively quickly and then acts as a more rigid barrier, while the internal part of the insulation structure, which is still relatively soft, cools more slowly, contracts, and subsequently solidifies. In principle, if it were also possible to pressurize the cable core from the conductor side, void formation in the most critical region of the insulation might be reduced.

The scope of this new project includes the design and construction of a special pilot extrusion line for XLPE-insulated cables, the manufacture of lengths of 15-kV cables by the new process, and electrical testing and evaluation of such cables. *Project Manager: Bruce S. Bernstein*

Figure 4 Cable follower loaded onto a cable and entering the ground at the end of a failed cable. The water and hydraulic fluid are now entrained in a single umbilical cord.

TRANSMISSION SUBSTATIONS

Substation control and protection systems

EPRI is sponsoring a project to develop a new substation control and protection system (RP1359). The goal is to achieve cost reductions and improved system performance by a distributed, microprocessor-based system. The microprocessor is a small, relatively low-cost component that could lead to a modular (therefore expandable) and easily maintained system.

The main technical challenge is to develop a system architecture that provides the best balance between cost and performance. Not unexpectedly, the topology of the substation poses a major problem to the system architects (*EPRI Journal*, October 1980, p. 44). To simplify the system design, one basic assumption was made—the control and protection system would be hierarchical, incorporating a computer in the substation that would act as the master of the system. With this assumption in mind, the following performance criteria were established for the system architecture.

- The critical protective relaying functions must operate even if the substation computer fails.
- Given sufficient redundancy in the system, the system will perform all critical processing even if there is a single component failure anywhere in the system.
- The system must not require more than one completely redundant data acquisition to satisfy the above criteria.

The single-failure criterion can realistically be met by permitting only a full set of redundant protective relaying processors and data acquisition units; the selected architecture permits this, while also meeting the last criterion, which limits the number of data acquisition units that can be used to satisfy the single-failure criterion. The last criterion was introduced to ensure an economically viable system.

After careful analyses of the system requirements, a system architecture was selected (Figure 5). At Level 1 are those functions that are common to the whole substation, and the substation operator can communicate with the entire system. At Level 2, all critical processing, which includes all the protective relaying functions, is done. At Level 3 the interfacing to the power system is handled. At this level, data are digitized for transmission to the protective relaying processors, and control commands from the system control center and Levels 1 and 2 are converted to outputs that operate the power equipment (e.g., breakers, switches).

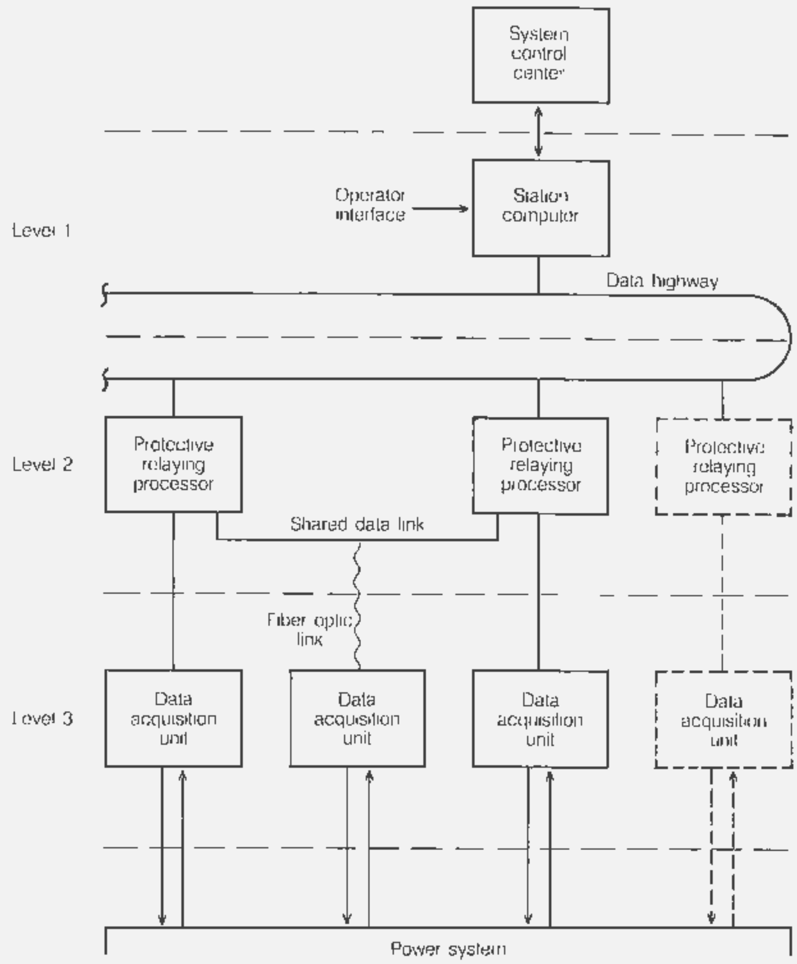
The communication equipment that is used between the different levels is obviously a key element in the system. A common high-speed data highway is the economical choice for communication between a small group of processors, particularly if any processor must be able to communicate with any other processor. The selected highway speed, one megabit per second, is possible by using economical large-scale integrated circuit technologies. The common highway concept should make system expansion relatively easy.

The data links between Levels 2 and 3 are also high-speed (one megabit per second) communication circuits. These links will incorporate an optical fiber whenever the data acquisition units are placed in the substation switchyard. The optical fiber is probably not necessary if conventional control wiring is used between the yard and the relay house, in which case the data acquisition units will be located in the relay house. In the foreseeable future, a hybrid system with some local relay house and some remote (switchyard) data acquisition units is most probable. The system has been specified with this requirement in mind. Economic considerations also indicate that at least two protective relaying processors must be able to access for control purposes and share the data from one data acquisition unit. This will permit introduction of system redundancy without jeopardizing the economic viability of the system.

To satisfy the first two selection criteria for the architecture, the highway should be redundant. This may be possible to do, but if the probability for a failure resulting in a short circuit of the highway cable can be kept low, a redundant highway may not be needed. This assumes that the highway continues to operate even if the station computer fails, which is a firm requirement. This also assumes that all the protective relaying processors have direct access by a data link to all the breakers that the processor needs to trip in order to clear a fault.

At this time, all the key system elements, except for the shared data link function, have been built and tested by Westinghouse Electric Corp., the contractor for systems development (RP1359-1). This work is expected to result in the installation of a demonstration system in a Public Service Electric and Gas Co. substation in 1984. A parallel development of a digital transmission line protective relay system, incorporating a protective relaying processor and data acquisition units by General Electric Co., has also reached the laboratory testing stage (RP1359-5). It is expected that a prototype relay will be installed in a substation for testing in 1983. *Project Manager: Stig Nilsson*

Figure 5 A hierarchical control and protection system for substations that incorporates a computer in the substation. High-speed communications (one megabit per second) are key to its operation, enabling the relaying processors to handle data both from the station computer on a data highway and from the data acquisition units by means of fiber optic links.



R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

WORLD OIL MODELS AND ISSUES: EMF STUDY NO. 6

EPRI created the Energy Modeling Forum (EMF) to improve the use and usefulness of energy models for the study of vital energy issues that influence the electric utility industry (RP875). EMF is now sponsored by DOE and the Gas Research Institute, as well as by EPRI. Administered by the Stanford Institute for Energy Studies, EMF operates through ad hoc working groups of energy model developers and users that conduct comparative tests of a range of energy models. The objective of the latest EMF study, which is discussed here, was to identify the strengths and weaknesses of 10 prominent world energy models by studying a number of world oil issues.

Oil prices

The high cost of oil imports, the threat of sudden supply interruptions, and the uncertainty about future oil market conditions pose grave difficulties for the oil-importing nations.

With the 1973 Arab-Israeli war and the deliberate reduction of oil production by Saudi Arabia and other Middle East countries, the world oil price jumped from $2.50/bbl in 1973 to $11/bbl in 1974. The subsequent world recession and adjustments of oil demand to the higher prices brought a slack world oil market; the oil price declined slowly in inflation-adjusted U.S. dollars. But following the 1978 Iranian revolution, world oil prices shot up again—this time to over $30/bbl. Late in 1980 there was widespread fear that the Iran-Iraq war would fuel another price escalation, but this escalation did not materialize. Rather, by early 1981, adjustments of oil demand to higher prices brought on another oil glut.

Although future world oil prices are unpredictable, analysis suggests that the chief uncertainty is not whether real prices will rise during the next several decades but rather how rapidly they will rise. An additional uncertainty concerns the duration and magnitude of the short-run decline in prices that began in 1981.

The models employed in the EMF study predict a soft oil market during the first half of this decade unless another supply disruption occurs, but by 1990 real prices can be expected to exceed their current high levels. The study indicates that although the trend of real prices will be upward over the next several decades, the pattern could be one of either steady upward price movements or sudden price jumps, followed by gradual and less dramatic declines.

The model-based analysis led to the following expectations.

▫ Conventional supplies of oil will increase slowly during the 1980s. The assumption of relatively constant oil production capacity of the Organization of Petroleum Exporting Countries (OPEC) and projections of declining oil production in the member countries of the Organization for Economic Cooperation and Development (OECD), balanced against moderate increases in oil production from the rest of the world, indicates that in the 1980s conventional oil production will grow much less rapidly than in the recent past. The study forecasts that by the end of the century, significant quantities of unconventional oil production from oil shale, coal liquefaction, and tar sands will be required.

▫ OPEC and the oil-importing developing countries can be expected to consume an ever-increasing share of future world oil production because of their industrialization and rapid economic expansion. If these nations increase their oil demands while conventional crude oil production grows slowly, OECD oil consumption can be expected to remain roughly constant or decline.

▫ High oil prices will be a strong motivating force for the substitution of natural gas, coal, nuclear, solar, and biomass energy for oil. Oil prices will also motivate increased energy conservation in all economic sectors.

▫ Despite the decline in OECD oil use, OECD countries will continue to depend on OPEC oil exports well into the twenty-first century. Although the economic problems of vulnerability to supply disruptions may decline by the turn of the century, high imported energy cost and uncertainty about future conditions will persist.

Impact of import reductions on oil prices

A major finding of the study is that oil import reductions can significantly reduce oil price growth (Figure 1). This effect was quantified by examining the average price

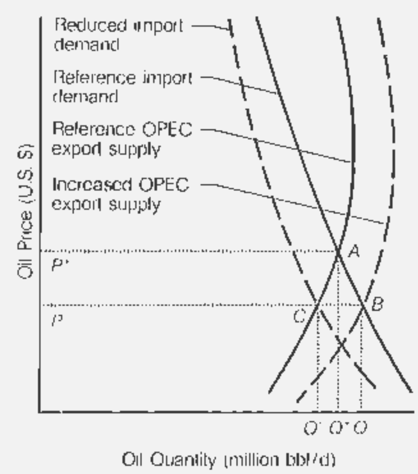


Figure 1 Price and quantity impacts of increased OPEC export supply or reduced import demand. The solid lines represent the reference case non-OPEC import demand (downward sloping) and the OPEC oil export supply curve (upward sloping). The initial equilibrium is at A with price P^* and quantity Q^*. An outward shift in the supply curve (broken line) leads to a new equilibrium at B with price P' and quantity Q'. An inward shift of the demand curve leads to equilibrium at C with a price P' and quantity Q''.

decline for each reduction of a million barrels of oil a day in the demand of oil-importing countries. The study calculated that by 1990, world oil prices would be reduced between $0.90 and $2.40 a barrel (1981 constant dollars) for each million-barrels-a-day reduction in oil import demand.

Because the member countries of OECD as a whole (or even the United States alone) import large quantities of oil, import reductions that moderate oil price increases can yield significant economic benefits to those countries.

Security of oil supplies

Because so much of the world's oil comes from a region that is politically unstable, the specter of oil supply disruptions remains. In fact, oil supply disruptions larger than those experienced in the past are possible. To examine the implications of such disruptions, the models were also applied to a hypothetical reduction in the production capacity of OPEC.

Under the assumptions of the reference scenario, world oil prices increase on an average $5–$12/bbl for each sudden reduction of a million barrels a day in OPEC crude oil output. However, the analysis shows that price jumps can be expected to be more than proportional to the size of the disruption. Similarly, the models indicate that the economic impact of supply disruptions could be immense. For example, if OECD is importing 25 million bbl/d at the time of the disruption (roughly current levels), an 8 million bbl/d reduction in OPEC output could lead to increased wealth transfers from the OECD nations to the oil-exporting countries of $300–$1100 billion per year—between 3 and 13% of the combined OECD gross national product. Unemployment and other macroeconomic consequences of the disruption could multiply these losses several times. And ratchet affects, which keep prices high long after a disruption, imply that economic losses would persist even after the disruption itself has subsided.

According to the analysis of price jumps during disruptions, price escalations could be moderated significantly if oil stocks are released or excess capacity is placed into production during the disruption. For example, the study indicates that for a large disruption, price jumps might be moderated by around $20/bbl if a million barrels a day are released from stockpiles or excess capacity is put into production. Thus, stockpiles or usable excess capacity could provide major benefits to the oil-importing nations.

The study also looked at the effects of gradual import reductions taken in advance of disruptions. Such reductions might lead to increases in excess capacity and thereby reduce the price escalation and economic costs of disruptions (Figure 2). For example, a 5 million bbl/d demand reduction undertaken prior to a 10 million bbl/d oil supply disruption was estimated to reduce its economic costs by between 30 and 90%.

Transition to oil substitutes

Beyond the next two decades, far-reaching changes in the world oil market may begin to occur. The study focused on the oil market effects of different levels of unconventional fuel supply, referred to as backstops, under plausible assumptions about future oil demand and conventional supply.

Under assumptions made about cost and future supply of backstop oil, it was found that the world oil price rises well above average backstop costs in most circumstances (Figure 3). In fact, massive quantities of backstop production were required before world oil prices declined to backstop costs in most scenarios. Although backstop technologies may not place a cap over world oil prices during the next 30 years, generally the greater the quantity of backstop production, the lower the world oil price. Similarly, the greater the available quantities of natural gas or other oil substitutes, the lower the world oil price. For example, the models indicated that by 2020, projected world oil price could be reduced between $1.20 and $3.90 per barrel, on the average, for each increase of a million barrels of oil a day in backstop production rates.

World oil modeling

A primary interest of EPRI in this study is in the insights on the usefulness of such models. In using the 10 models of the world

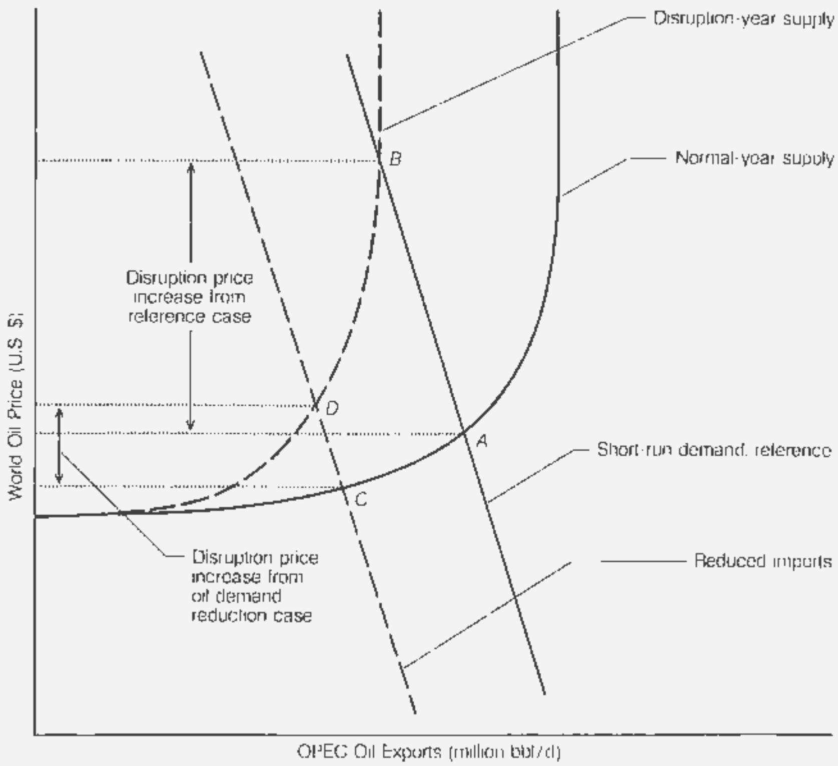


Figure 2 Effects of import reduction measures on disruption impacts. The solid lines represent the reference case non-OPEC oil import demand (downward sloping) and the OPEC normal-year oil export supply curve (upward sloping). The equilibrium in a normal year is at *A*. In a disruption year, the supply curve is shown by the upward sloping broken line and the new equilibrium will be at *B*, a much higher price than at *A*. If import reduction measures cause-reduced oil demand, then in a normal year the price will be reduced slightly (equilibrium at *C*, not *A*), and in a disruption year, the price will be reduced significantly (equilibrium at *D* rather than *B*).

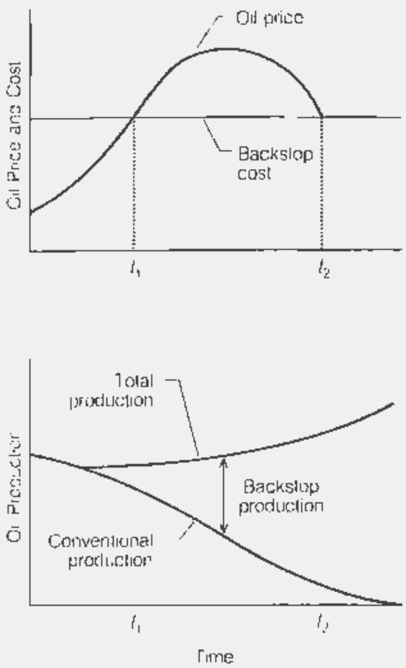


Figure 3 Effect of backstop production on world oil price. In this simplification, all unconventional oil sources are treated as a single backstop source with a constant production cost. Oil prices pass through three distinct phases. Early on, only conventional oil is produced; its price rises as this resource is depleted. At time t_1, when the price of conventional oil first reaches the backstop cost, backstop production begins. If, as seems likely, unconventional oil production capacity can increase only slowly at first because of limited capital, environmental constraints, and so on, the price of oil may continue to rise above backstop costs. If backstop capacity eventually grows to the point where it (along with conventional oil production) can meet demand at backstop costs, oil prices will decline to the level of these costs. This is the third phase, after t_2, where backstop costs set the world oil price.

oil market, the EMF study reached a number of conclusions about the current generation of models. The 10 models use a striking diversity of assumptions and approximations. They differ in their degree of product coverage and disaggregation—some represent oil markets only, ignoring other energy markets; others represent oil markets within the context of all major energy commodities; and still others treat all energy as a single broad aggregate.

The models differ widely in their treatment of OPEC decision making: in some, virtually all OPEC choices are exogenous; in others, OPEC is treated as an optimizing monopolist; and in still others, rules of thumb for OPEC decision making are simulated.

The models differ in their representation of oil demand. All but one assume that demand responds slowly to price—short-run price elasticities of demand are far smaller than long-run elasticities. Only four models include any effect of oil prices on economic activity, even though the existence of such an effect is well established. None includes considerations of international balance of trade or represents the consequences of trade imbalance for economic growth or for oil import demand. Finally, none includes the macroeconomic losses associated with the unemployment of labor and capital equipment during a severe disruption of oil supplies.

The differences and admitted limitations of the models reflect the current imperfect understanding of the world oil markets. The oil market is a highly complex, uncertain network of centralized and decentralized decision-making processes. Political shifts, changes in weather, war and revolution may cause rapid, unforeseen changes in oil markets. To the extent that domestic policy and planning decisions require information about world oil trends and options, more research, modeling, and analysis should be directed toward the world oil and energy markets.

The final report on the world oil study was published in May 1982 (EA-2447-SY). The report contains a detailed analysis of the model-based results, as well as conclusions reached about the current generation of models. The report also suggests areas for fundamental research that could improve our ability to model world oil markets in the future. *Project Managers: Shishir Mukherjee and Stephen Peck*

TOXICOLOGY OF CHEMICALS IN THE UTILITY WORKPLACE

Public concern has been growing in recent years about the effects of chemicals on human health. Occupational exposure to chemicals—especially those whose effects are not seen until many years later—is a particular worry for workers and employers alike. Utilities, like many other industrial operations, need extensive information on the potential hazards of the chemicals used on site. Chemical toxicology is complex, with wide variations in toxicity among chemicals and varying degrees of risk, depending on use and degree of exposure. Obtaining accurate information is critical to utilities designing chemical monitoring and control programs in the workplace. RP2222 will identify 25–50 chemicals of potential high risk in utility uses.

Utilities need information on the nature of the chemicals used in their generation and distribution facilities, the potential long-term health effects, and the possible exposures of workers. However, utilities do not have a complete and systematic inventory of those chemicals specific to utility use. RP2222 will provide utilities with the up-to-date technical information they need to manage chemical use in the workplace.

The three-year EPRI project will proceed in two phases (Figure 4). In Phase 1, researchers will evaluate the toxicity of chemicals commonly found in the utility workplace; in Phase 2, they will identify those suitable for a more detailed toxicology assessment. The evaluation will focus on such long-term toxicologic hazards as carcinogenicity, mutagenicity, teratogenicity, reproductive toxicity, and neurotoxicity. The goal is to produce a list of potentially hazardous chemicals that may occur in sufficient amounts in utility sites to be of concern.

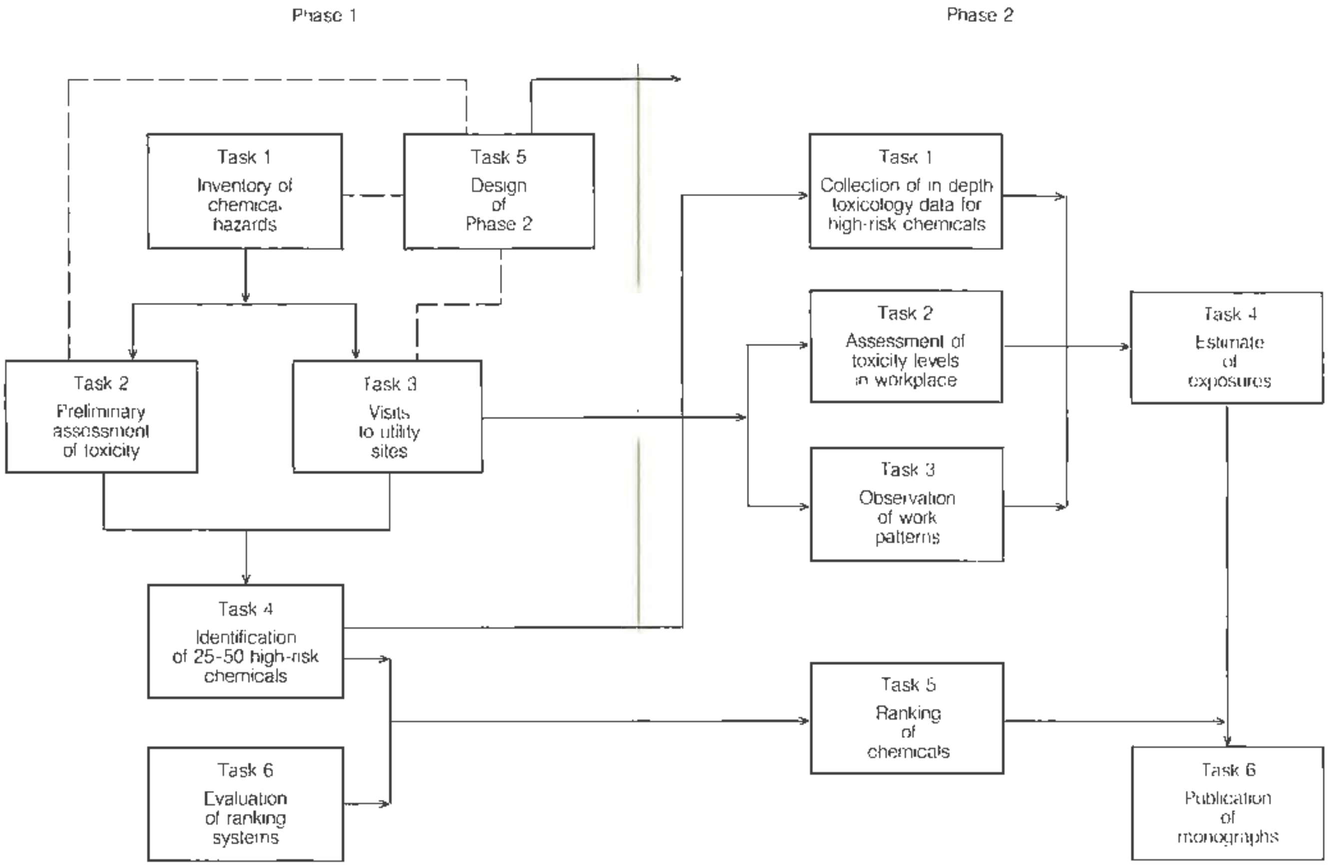
In cooperation with utility personnel, researchers will begin Phase 1 by assembling an inventory of chemicals used in the utility workplace. A preliminary search of computerized bibliographic data bases will be used to assemble required information on the toxicologic, physical, and chemical properties of all the compounds in the inventory. Toxicology experts will first screen the list for chemicals known or suspected to be associated with long-term health effects in people or animals. A second screening, conducted by toxicologists and industrial hygienists, will eliminate compounds that—based on current knowledge of their use, the amount present in the workplace, or other relevant factors—do not seem to pose a significant occupational hazard.

At this point, researchers will perform a detailed review of the scientific literature to obtain enough information to design Phase 2, while toxicologists and industrial hygienists will visit representative utilities to observe industrial hygiene and other work practices. Project designers believe that this information will help create a list of 25 to 50 substances for closer scrutiny in the project's second phase.

A second product of Phase 1 will be a system for ranking chemicals by their potency or potential hazard to health in the utility workplace. Researchers will develop the system based on their evaluation of existing systems and their applicability to utilities' needs. The resultant system will guide the final work of Phase 2.

Phase 2 of the project will evaluate in detail the risks posed to workers by the substances targeted in Phase 1 and will suggest

Figure 4 Tasks for the two phases of RP2222. Phase 2 will focus on 25–50 chemicals identified through preliminary evaluation and screenings in Phase 1.



methods for controlling workers' exposure to an acceptable level. (Standards set by regulatory agencies such as OSHA or EPA will guide the definition of "acceptable" levels of risk.)

In the first stage of Phase 2, researchers will collect detailed toxicity information on the selected chemicals for cellular and subcellular systems as well as for animals. The next step will be to estimate worker exposures based on available information in utilities and comparable industrial operations. Direct on-site observations, if needed, will provide descriptions of work patterns that can shed light on worker exposures.

In Phase 2, project leaders expect three benefits from ranking the chemicals by their potential for long-term health hazards.

- Identification of chemicals requiring early validation of occupational risk
- Identification of chemicals that may pose a significant hazard but that require toxicologic testing
- Identification of chemicals for further monitoring

Project researchers will also issue a series of short reports on selected chemicals that will focus primarily on long-term health effects but will also include information on medical surveillance, handling, and disposal practices required by EPA, OSHA, and other regulatory agencies. These monographs will outline industrial hygiene and occupational medicine concerns, tailored to the needs of utility health and safety personnel. The first monograph will be available at the end of the first year of the project.

A group of three outside scientists, two toxicologists and an expert in industrial hygiene, will advise EPRI during the project. In addition, utility advisers will review the work for its relevance to utility operations.

Phase 1 of the project began in November 1982; completion is scheduled for the second quarter of 1984. *Project Manager: Walter Weyzen*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

ZINC CHLORIDE BATTERIES FOR UTILITY APPLICATIONS

The several potential advantages batteries have over other energy storage alternatives continue to spur the development of zinc chloride and other advanced batteries (EPRI Journal, *October 1976, p. 6; April 1980, p. 8; September 1980, p. 47; October 1981, p. 6). Research on zinc chloride batteries for utility application has been part of the Energy Storage Program since 1974; DOE has also funded battery research since 1978. Reliable operation of 50-kWh modules at 62–65% electrochemical energy efficiency has recently been achieved. The coordinated DOE–EPRI plans call for a test of a 500-kWh prototype battery at the Battery Energy Storage Test (BEST) Facility by mid 1983 (RP255).*

During the summer of 1980 a DOE-sponsored program culminated in the assembly and evaluation of two 50-kWh prototype battery modules. However, module performance was unreliable and inefficient (i.e., less than 60%, well below the target of 63–65%).

One problem with the first two prototypes' operation was that the chlorine hydrate–formation pump (also called gas pump) became plugged with hydrate. This obstruction resulted from a blocked filter screen at the inlet to the oritice upstream of the hydrate-formation heat exchanger. In addition, the PVC case lining delaminated from the fiber-reinforced polyester outer jacket. Leakage ensued and impurities contaminated the electrolyte phase, and significant amounts of nitrogen introduced into the chlorine in the gas phase abruptly decreased module output and/or affected its ability to accept charge.

EPRI, DOE, and Energy Development Associates (EDA) funded a project to redesign the system, beginning in the fall of 1980 (RP226-05). The effort involved engineering design, manufacturing methods development, test sample fabrication, and extensive testing. The new system was successfully demonstrated in the spring of 1982, when a 50-kWh module funded by DOE first gave

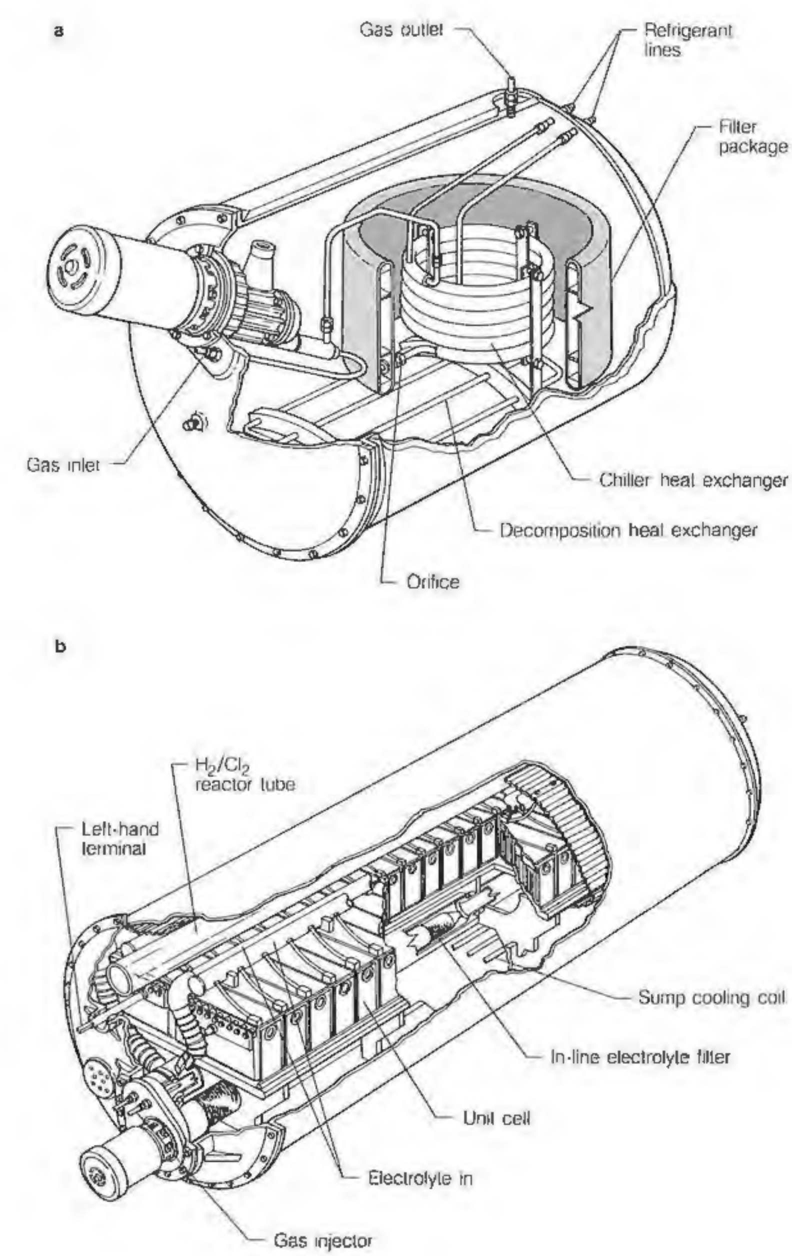


Figure 1 New zinc chloride module configuration resulting from EPRI–EDA studies: (a) store section containing hydrate-formation pump, water-chilling heat exchanger, filter, and hydrate decomposition coil; (b) section containing the electrochemical stack, electrolyte pump, and manifolding.

satisfactory performance for more than 150 cycles.

System redesign

A study of the ways to increase the case's mechanical ruggedness, improve overall system reliability and ease of operation, and limit development costs concluded that separating the stack and store compartments into two cylindrical, horizontally oriented vessels was cost-effective. Figures 1 and 2 show the new module configuration. One sacrifice had to be made with this single 50-kWh module design: It took more floor space for a given amount of output. The goal of 8 kWh/ft^2 (87 kWh/m^2) of floor space was decreased to approximately 3 kWh/ft^2 (33 kWh/m^2). However, conceptual designs in which the modules are stacked three high promise a practical arrangement yielding more than 8 kWh/ft^2 (87 kWh/m^2).

The redesign effort addressed all causes of the unsatisfactory performance in the first prototype design. Dye marker added to the electrolyte showed that the loose-fitting plastic frames holding the porous wafer chlorine electrodes allowed substantial amounts of electrolyte to flow from a few cells directly to the sump. This problem was a principal cause of coulombic loss. Complete redesign of the injection-molded frames and other changes in submodule hydraulic design and assembly have resulted in module and submodule hydraulic integrity.

Another cause of coulombic efficiency loss was that the pore sizes in the graphite of the flow-through chlorine electrodes were not uniform. The size difference resulted in the uneven flow of dissolved chlorine and excessive zinc corrosion. Union Carbide Corp. and Airco, Inc., are now providing porous graphite with an average pore diameter of 25 ± 5 μm and a permeability in the range $5 \pm 2 \times 10^{-8}$ cm^2. Particularly important is the elimination of pores of diameter greater than about 40 μm. To further ensure even distribution of electrolyte flow, each pair of porous graphite wafers is matched in permeability. The impact of these requirements on graphite and assembly cost remains to be determined.

The porous graphite is electrochemically activated to reduce the polarization losses at the chlorine electrode. The most common treatment consists of passing a current of 30 to 50 mA/cm^2 with the porous electrode as the anode in dilute acid (oxidizing electrode on charge) to etch the surface. Many other methods, including plasma etching, gas phase oxidation, and chemical etching, were also investigated. At this writing the anodic etching method is preferred. Activation is by no means thoroughly understood. It increases specific surface area and modifies the chemical nature of the graphite surface. Further improvement in voltaic efficiency from the 85–86% presently obtained to the region of 90% is expected to result from additional studies (RP226).

It has been clear since the inception of the project that the major loss in coulombic efficiency results from the chemical reaction between deposited zinc and dissolved chlorine. A critical aspect is the hydrodynamics of the flow between the chlorine electrode and the zinc electrode because it controls the transport of chlorine to the zinc anode. Under EDA–EPRI sponsorship, Wayne State University is investigating this topic. Figure 3 depicts the effect of cell gap on chlorine mass-transfer coefficient, which is inversely proportional to the coulombic efficiency. On the basis of this result, the interelectrode gap was increased from 0.20 to 0.33 cm in the new design.

However, an undesirable consequence of the increased cell gap is a concomitant increase in internal resistance. This can be partially compensated by increasing the concentrations of supporting electrolytes, potassium chloride (KCl) and sodium chloride (NaCl), from 2 *M* and 0 *M* to 4 *M* and 1 *M*, respectively. The conductivity of the more highly supported electrolyte (2.5 *M* $ZnCl_2$ + 4 *M* KCl + 1 *M* NaCl) is approximately one-third greater than that of the usual 2.5 *M* $ZnCl_2$ + 2 *M* KCl. An additional benefit of using the more concentrated electrolyte is a decrease in the solubility of chlorine, which will reduce the corrosion current and increase coulombic efficiency. This approach has been proved valid at the submodule (20-V) level.

The so-called corrosion current, a faradic equivalent of the rate of the chemical reaction between dissolved chlorine and zinc, can be reduced in impact by increasing the operating current density. Operation at 50 mA/cm^2 instead of the previous 33 mA/cm^2 has been shown to be entirely practical with the new submodule designs. Given a higher current density, more zinc will be deposited in the fixed charge period of 7 h. The increased cell gap readily accommodates this. Module energy storage capacity is directly proportional to the amount of zinc deposited. A thicker deposit requires fewer graphite electrodes to achieve a given total energy storage. The end result has been a module with one-third less graphite—the most expensive material in the battery.

Operation of cells/batteries in series/parallel arrays is necessary to achieve useful voltage and current output. The possible effect of such operation on system reliability has been discussed in an EPRI report (EM-1890). Each battery system has electrochemical characteristics of its own that dictate the optimum arrangement. Zinc chloride battery unit cells are almost certain to fail in a short circuit caused by zinc growths bridging the electrodes. This effectively reduces the output of the particular series string by somewhat more than 2 V. For a given power the remaining cells in the string will pick up the load. The only adverse effect is a loss in efficiency of the entire string. Clearly, the longer the string (i.e., the more

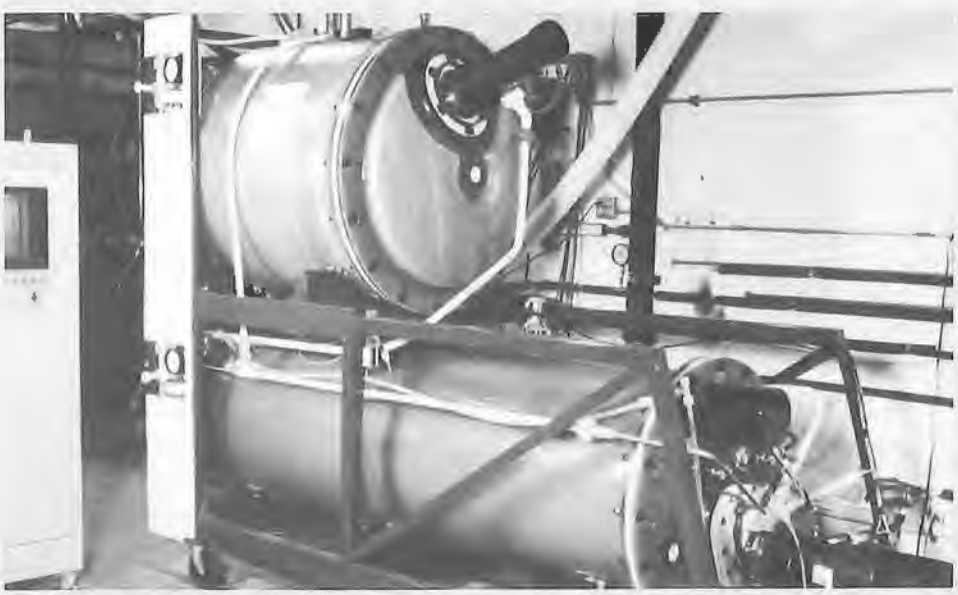
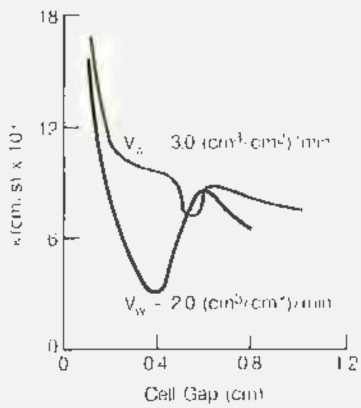


Figure 2 Module under test at EDA facilities.

Figure 3 Typical result of analysis of the module, showing the effect of interelectrode cell gap on chlorine mass-transfer coefficient (k) at a constant current density of 30 mA/cm². Minimum k at a gap of about 0.4 cm will give the maximum in coulombic efficiency (i.e., coulombic efficiency decreases as k increases).



cells connected in series), the less the percentage impact. Accordingly, in the new stack design two submodules of 24 cells (48 V) in series are connected in parallel as opposed to the earlier arrangement of six submodules of 10 cells in series. The new design should increase the overall reliability. Shunt currents through parallel paths in the electrolyte manifold have been held to a minimum through careful design. The overall loss in efficiency resulting from such parasitic currents is estimated to be about 1.5%.

The propensity of zinc to grow dendrites during electrodeposition plagues all secondary battery systems with zinc anodes. Careful attention in design is required to minimize stagnant electrolyte regions between the electrodes and to eliminate sharp corners and edges on the zinc deposition substrates. In the final assembly, corrosion-resistant and insulating masking of unwanted or unnecessary electrode and connector surfaces (graphite busbar in the present zinc chloride design) prevents dendrite formation.

Results of the operation of the first two prototype modules showed the need to improve the mechanical and hydraulic components: two pumps, two control valves, and three heat exchangers. Prototype pumps were delivered late in 1980 and thus were not incorporated in the first prototypes. Later module prototypes are using both the electrolyte and hydrate-formation pumps, the former with complete success and the latter with some difficulty.

Diaphragm valves, which are packless and motor-operated, have been selected as more reliable than the solenoid valves used earlier. Cycle tests have proved these to be quite satisfactory.

Only the hydrate-formation heat exchanger is complex enough to be of concern. Titanium is the metal of choice for exposure to the moist chlorine environment. The tube-in-tube design has proved to be completely satisfactory for much lower cost than the earlier shell-and-tube model.

The pumps were designed and fabricated by Ingersoll-Rand Research, Inc., specifically for the 50-kWh module electrolyte circulation and hydrate formation from the following specifications.

- Magnetic coupling of the ac electric motors to the pumps
- Pump bodies of injection moldable PVC and titanium for shafts to eliminate any possibility of electrolyte contamination
- Production costs to be approximately $300 per pump
- Centrifugal pump for electrolyte
- Positive displacement gear pump for hydrate formation

System performance

An extension to the DOE–EDA contract called for the fabrication and operation of two 50-kWh prototype modules to validate the new design features. Concurrently RP226-05 required the fabrication and operation of an additional 50-kWh module. The efficiency goal of this module is 70%, more than the 63–65% for the DOE modules, which do not contain all the design improvements.

The first of these new prototype modules (designated number 3) began operation in March 1982. Since that time it has been cycled daily (weekdays only), achieving over 150 cycles as of this report with only one serious interruption. Performance has been very stable with an electrochemical energy efficiency of ~61%. The one interruption was caused by a defect in the PVC insulation of the internal terminal connector. After the insulation was replaced and impurities removed electrochemically from the electrolyte, the module was again placed in operation (cycle 80). Prototype 4 has been in operation for a shorter period of time and has performed much like prototype 3.

The submodules first introduced into the EPRI-funded module (prototype 5) were defective; consequently, the performance was erratic. New submodules were installed in September 1982. Because of continued difficulties in obtaining a reliable hydrate-formation pump, extended operation of prototype 5 is yet to be achieved.

Performance of the redesigned zinc chloride modules can be summarized as follows.

- Although the modules are substantially more efficient than the first prototypes, coulombic efficiency falls a few points short of the goals.
- Mechanical component reliability has been good; however, hydrate-formation-pump reliability remains a concern.
- Chemical degradation as evidenced by electrolyte contamination is very slow; the original electrolyte is still used after 150 cycles.
- Carbon dioxide buildup in the gas space is slow, requiring that this volume be flushed with cylinder chlorine about once every 20 cycles. Whether inert gas rejection by means other than periodic flushing with chlorine is required remains unanswered since it is not certain that steady-state operation has been achieved (i.e., aging continues).
- There has been little noticeable degradation in performance with time or cycles over the test period.

Evidence points to rough or nodular zinc deposits as the cause of lower-than-expected coulombic efficiencies. These nodules, which appear toward the end of the charge cycle, disrupt the electrolyte flow, so that dissolved chlorine has easier access to the zinc. Consequently, a greater amount of zinc is dissolved chemically. The ongoing RP226-05 will study the causes of the sudden reappearance of this phenomenon.

The results described above justify the evaluation of a 10-module (500-kWh) zinc chloride battery in the BEST Facility. Battery fabrication and installation will be jointly funded by DOE (50%), EDA (25%), and EPRI (25%). The EPRI share of funding of the battery evaluation will be provided by RP255. Two years of testing are planned, beginning in mid 1983. If early results are satisfactory, battery size may be increased by about 75% (to 1000 V). That voltage is the limit of the BEST converter and represents a more realistic system test.

Researchers expect to have solved the zinc deposition problem and to have 70% or greater electrochemical energy efficiency by the time the BEST evaluation is complete. Successful results at the BEST Facility will be followed by efforts to begin commercialization by installing a larger battery on a utility grid or at a customer site for commercial demonstration purposes. *Project Manager: David Douglas*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

BWR WATER CHEMISTRY

Many of the stress corrosion problems in boiling water reactors (BWRs) result from the presence of a very small amount of dissolved oxygen in the reactor water. Radiolysis in the reactor core continually decomposes a small amount of the very pure water used in BWRs into free oxygen and hydrogen. Most of the gas is stripped from the water by the steam, leaving only trace amounts of oxygen and hydrogen dissolved in the reactor water. Although the amount of dissolved oxygen is only about 200 ppb, it is sufficient to facilitate stress corrosion cracking. Hydrogen water chemistry can reduce dissolved oxygen to a level that will no longer facilitate stress corrosion.

Pipe cracking in BWRs first came to the attention of U.S. electric utilities in 1974. This problem has resulted in costly repairs and lost operating time. The potential seriousness of the problem was recently emphasized by the discovery of cracks in large-diameter (26-in; 660-mm) recirculation piping at a domestic BWR. These cracks necessitated replacement of the complete recirculation piping system and will cost 12 to 18 months of operating time.

Earlier EPRI reports (*EPRI Journal*, September 1981, p. 6; November 1981, p. 18) have helped familiarize the industry with the various factors involved in pipe cracking. In most cases, cracks have resulted from intergranular stress corrosion cracking (IGSCC). This status report describes how changing reactor water chemistry can help prevent IGSCC.

Three conditions must be present simultaneously for IGSCC to occur: stress, a sensitized microstructure, and an environment (water chemistry and temperature) that will facilitate cracking. Theoretically, no pipe will ever crack if any one factor is completely eliminated. Eight pipe-cracking remedies have been developed: three that affect stress, three that affect sensitization, and two that affect environment (Table 1). By their very nature, all the stress and sensitization remedies are limited to the specific component to which they are applied. For example, induction heating stress improvement affects cracking in the pipe weld to which it is applied; it does not affect any other weld. Only the water chemistry remedies have the potential of protecting the whole system.

The water in a BWR is similar in purity to laboratory distilled water. It is converted into steam by reactor core heat, condensed into liquid again after passing through the turbine, and reconverted into steam on reentering the core. This process is repeated continuously.

During reactor operation, radiolysis in the reactor core continually decomposes a small amount of water to form free oxygen and hydrogen. Most of the oxygen and hydrogen is stripped from the water by the steam and is subsequently removed from the water circuit by special equipment in the condenser. However, about 200 ppb oxygen and 12 ppb hydrogen remain dissolved in the water in the core when the reactor is at the steady-state full-power operating temperature (288°C; 550°F). During reactor startups and shutdowns oxygen concentration varies with temperature (Figure 1). The important question of which temperature-oxygen combinations facilitate IGSCC has been answered in part under EPRI research (RP1332 and RPT115). The shaded IGSCC danger zone in the figure represents those combinations.

Table 1
CAUSES AND REMEDIES FOR BWR PIPE CRACKING

Cause	Remedy
Stress	Induction heating stress improvement
	Heat sink welding
	Last-pass heat sink welding
Sensitization	Solution heat treatment
	Corrosion-resistant cladding
	Alternative materials
Environment	Hydrogen water chemistry
	Impurity control

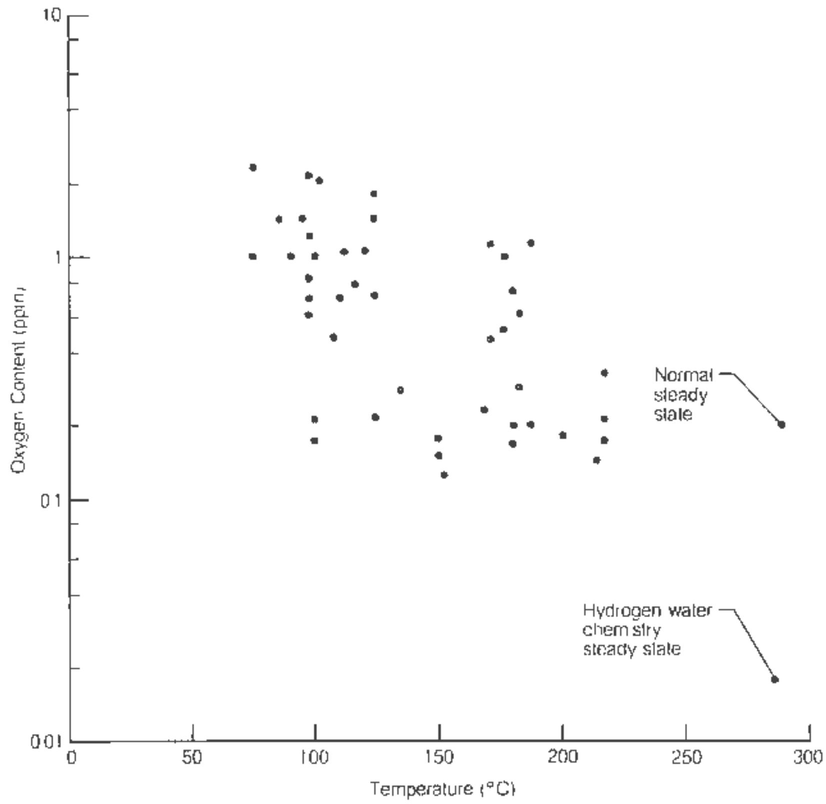
Reducing oxygen levels during reactor startups and shutdowns by deaeration has been highly publicized in the BWR industry. Although helpful during transients, this remedy does little, if anything, to reduce pipe cracking during steady-state conditions (RP1332-2, RPT112-1, RPT115-3, RPT115-4). Deaeration does not affect oxygen levels during steady-state operating conditions, which definitely facilitate IGSCC. The amount of time spent at steady state is about 140 times greater than the amount of time spent in startups. Therefore, to reduce IGSCC further, it is necessary to change water chemistry during steady-state conditions.

Hydrogen water chemistry

In hydrogen water chemistry, small amounts of hydrogen gas are added to the reactor feedwater. In the reactor core the added hydrogen recombines with oxygen and other radiolysis products to suppress the net amount of oxygen produced at the steady-state temperature (Figure 1).

Although hydrogen water chemistry experiments were conducted over 20 years ago in several early Norwegian and U.S. test reactors, the concept was not further developed until 1979, when the Swedish utilities and ASEA–Atom conducted a short eight-hour test of hydrogen water chemistry at Oskarshamn-2 and demonstrated that hydrogen water chemistry was economically feasible. In 1981 the Swedes conducted a second test at Oskarshamn-2 for four days and obtained detailed water chemistry measurements. These tests showed that hydrogen water chemistry lowered the oxygen concentration to levels that would no longer be expected to facilitate stress corrosion. However, no actual in-reactor corrosion tests were performed. In June 1982 DOE funded

Figure 1 The shaded area represents the temperature-oxygen combinations that facilitate IGSCC in high-purity water. The data points are examples of temperature-oxygen combinations that have been measured in operating BWRs during startup, shutdown, normal steady state, and hydrogen water chemistry steady state.



a 30-day hydrogen water chemistry experiment at Commonwealth Edison Co.'s Dresden-2 plant. During this experiment, EPRI sponsored in-reactor stress corrosion tests that helped confirm hydrogen water chemistry as a powerful antidote for stress corrosion problems (RP1930-2). A $1 million EPRI laboratory research project on hydrogen water chemistry, which has been in progress for two years, supports this conclusion (RP1930-1).

The combined results of the in-reactor and laboratory IGSCC tests show that the oxygen level must be suppressed to 20 ppb to eliminate IGSCC completely. For example, during the Dresden-2 test, a severely sensitized sample of stainless steel was tested under extreme stress and strain, and absolutely no IGSCC was detected. In laboratory tests on full-scale pipes the growth rates of preexisting cracks have been slowed by a factor of 10 as a result of hydrogen water chemistry. If no cracks are present before hydrogen treatment of water, no new cracks are expected to start.

To achieve an oxygen level of 20 ppb during the Dresden-2 test, it was necessary to add 1.5 ppm hydrogen to the feedwater and to use pure oxygen in the off-gas system instead of air. The total cost of both hydrogen and oxygen was less than $1000/day. If a BWR had a 70% capacity factor and a remaining lifetime of 20 years, the total would be about $5 million. Equipment installation would cost an additional $1 million. In contrast, replacement of a complete recirculation piping system is estimated to cost on the order of $500 million, including the cost of replacement power.

Although the stress corrosion benefits from hydrogen water chemistry are expected to be very high, at least one negative side effect exists. The amount of the radioactive isotope nitrogen-16 (N-16) in the steam will increase. The N-16 is formed in the reactor core by the nuclear reaction: oxygen-16 + neutron $\longrightarrow$ nitrogen-16 + proton. Under normal water chemistry conditions the N-16 reacts with dissolved oxygen to form nitrate (NO_3^-), which is soluble in the reactor water. Under hydrogen water chemistry conditions there is not enough dissolved oxygen to react with the N-16 to form NO_3^-; the N-16 combines with the hydrogen to form ammonia, NH_3. Ammonia is a volatile gas and is therefore removed from the water by the steam. The N-16 is a very unstable isotope and decays with a half-life of 7.11 s, giving off high-energy gamma rays. Because more N-16 ends up in the steam when hydrogen water chemistry is used, the steam lines and steam turbine will emit more gamma radiation than when normal BWR water chemistry is used. At Dresden-2, the amount of N-16 gamma radiation increased by a factor of 5 during the hydrogen water chemistry test. The turbine is heavily shielded and therefore the increase in N-16 did not significantly increase the radiation dose rate to plant personnel. In general, the N-16 side effect was manageable during the tests at Dresden-2. When maintenance crews had to enter an area where N-16 radiation was high, the hydrogen injection was stopped, and N-16 radiation levels quickly returned to normal. After the maintenance crew left the area, the hydrogen injection was resumed.

The major uncertainties about hydrogen water chemistry revolve around the possibility of long-term negative side effects. The two most important concerns are the hydrogen embrittlement of the nuclear fuel cladding and the redistribution of corrosion products (radiation buildup) within the plant. Although the best technical judgment available indicates that the possibility of either of these effects becoming unmanageable is extremely remote, there is no data base on which to build firm conclusions. At least one fuel cycle with hydrogen water chemistry will be required before a recommendation can be made to the utilities. EPRI is developing a long-term in-reactor test program to address these major uncertainties.

Control of impurities

Although reactor water contains impurities in small amounts (at the ppm or ppb levels), BWRs generally operate with high-purity water. For example, NRC guidelines specify that reactor water chloride (Cl) concentration be kept below 0.2 ppm and the conductivity below 1 μS/cm during plant operation. A solution containing 1 ppm of sodium chloride (NaCl) would have a conductivity of about 2 μS/cm and a Cl concentration of 0.6 ppm. Therefore, 1 ppm of NaCl would exceed the NRC specifications. The results of EPRI research projects have shown that maintaining water purity may be just as important as controlling oxygen levels (RP1563-2, RPT115-3, RPT115-6). Impurities increase the size of the IGSCC danger zone.

In accelerated laboratory IGSCC tests as little as 1 ppm of certain impurities eradicated hydrogen water chemistry benefits. To benefit from hydrogen water chemistry, utilities will have to control both oxygen levels and conductivity. Reactor water with only 20 ppb oxygen and a conductivity in the vicinity of 0.2 μS/cm may eliminate any possibility of IGSCC. EPRI has recently stepped up its research to understand the role of impurities in an effort to produce cost-effective water chemistry guidelines. *Project Manager: Michael Fox*

VALVE RESEARCH

The primary goal of valve research in EPRI's Nuclear Power Division is to reduce the amount of plant unavailability attributable to valves in LWR power plants. These R&D activities seek to improve valve maintenance practices and valve performance and reliability and thus reduce the cost of producing electricity. EPRI's initial effort in this area was an assessment of industry valve problems conducted in the mid 1970s (NP-241). It was found that nuclear plant unavailability attributed to valves, valve actuators, and associated control circuits represented approximately three forced outages per plant per year, with an average outage duration of about two days. The value of such unavailability is significant. A study reported in the June 1982 EPRI Journal *(p. 18) indicates that a 1% availability improvement in base-load coal and nuclear generating units combined would represent savings of $2.2 billion nationwide over the seven-year study period.*

In the initial assessment of industry valve problems, which was conducted by MPR Associates, Inc., the concept of key valves evolved. These are valves whose malfunction can result in a forced plant outage, a power reduction, or an extension of a planned outage. It is basically to these valves that the EPRI research effort is directed.

The study concluded that only a small percentage (5–10%) of the total valve population in a nuclear power plant is applied in such a way that failure would result in a forced outage. It should be noted that these key valves are not necessarily safety-related valves. No major differences were found between PWRs and BWRs regarding the causes (seat leakage, stem leakage, actuator malfunction) of valve-related shutdowns.

The study also concluded that forced outages attributable to valves are underreported because of an umbrella or shadowing effect—situations where a valve requires maintenance or repair work during an outage attributed to another system or component. Thus, although the valve could be considered a contributing cause of the outage, this is not reflected in the reported data.

Nuclear plant data collection and evaluation systems originally had many shortcomings. As a result of improvements in these systems, data quantity and usefulness have been increased. Other existing sources of information remain to be assimilated, however, to achieve a comprehensive view of the problem. EPRI's limiting-factors analysis studies, the findings of which are published in four reports (NP-1136 through NP-1139), provide further insight into the causes and the magnitude of nuclear plant availability losses attributable to valves.

On the basis of the efforts described above, two areas were selected for initial EPRI R&D attention: the seat leakage performance of main steam isolation valves (MSIVs) in BWRs and valve stem packing improvements for both PWR and BWR application.

Figure 2 presents a cutaway view of a representative MSIV with the valve bonnet and the actuator removed. Two identical MSIVs are installed in series in each BWR steam line. Technical specifications for BWR plants establish maximum allowable seat leakage rates for MSIVs and require the periodic testing of each valve to verify that this requirement is met.

Work was initiated in early 1979 with Atwood and Morrill Co., Inc., a manufacturer of MSIVs, and General Electric Co., the nuclear steam supply system contractor for BWR plants, to develop a comprehensive test program on MSIV seat leakage performance (RP1243-1, RP1389-1). The goals were first to identify the factors that affect the valves' capability to meet the seat leakage criteria imposed by the local leak rate test (LLRT) and then to identify and verify the effectiveness of corrective actions for improving valve leakage performance.

The program evaluated the effects of such factors as local residual stresses from valve installation welding; forces and moments applied by the connecting pipe; mechanical cycling; thermal cycling; excessive wear and corrosion of critical valve surfaces; and poorly controlled maintenance practices. Of the factors investigated, corrosion of the valve seating surface (or changes in the friction coefficient) and inadequate maintenance practices were found to be the most significant contributors to the seat leakage problem. Program results are reported in NP-2381 and NP-2454.

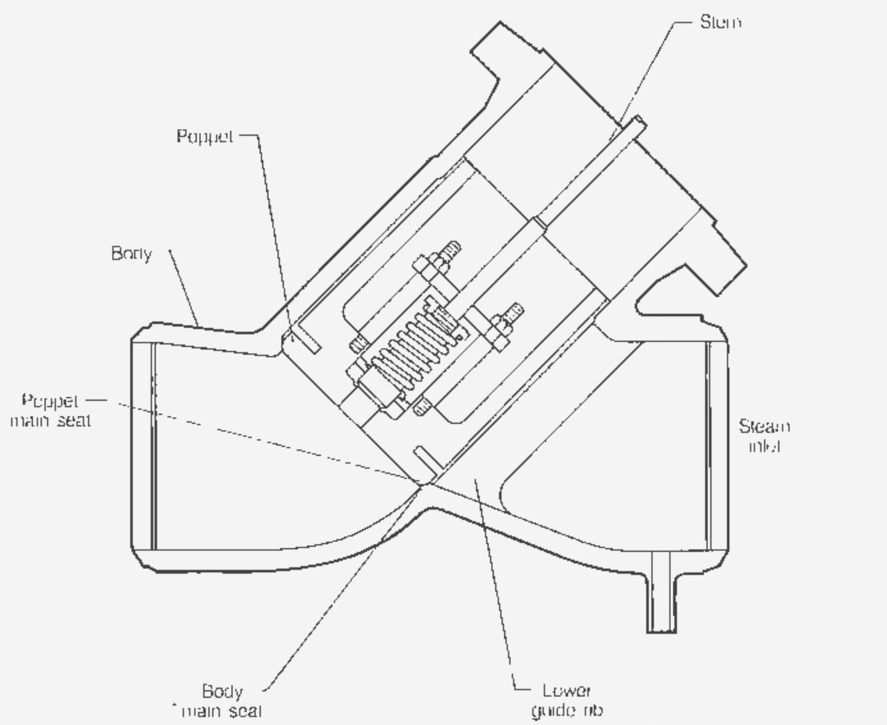
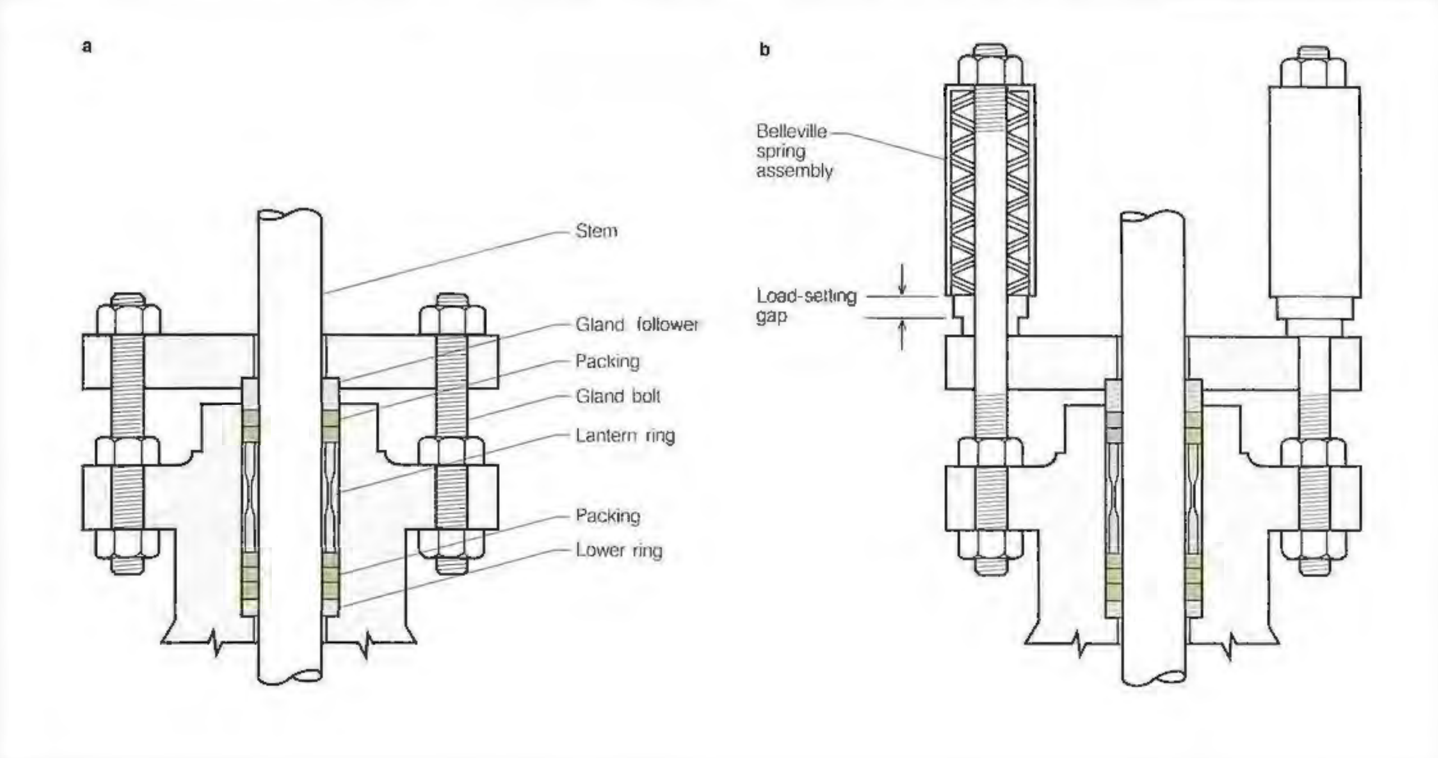


Figure 2 BWR main steam isolation valve. EPRI has sponsored a test program to determine the factors that affect valve seat leakage performance and to evaluate ways to improve this performance.

Figure 3 A conventional double-packed valve stem seal (a) and a live-loaded double-packed stem seal (b). Live loading, a method of maintaining compression on the packing, has been found to be effective in reducing packing leakage. In this design Belleville springs are used to produce the packing load.



Increasing the force that was applied to close the test valve was found to have a very favorable and predictable effect in reducing its leak rate. Some utilities have recently indicated that they plan to increase the closure force in MSIVs by increasing the operating air pressure applied to the pneumatic actuator. Closure force can also be increased during leak rate testing by applying the LLRT differential pressure above the poppet—that is, in the direction that tends to close the valve (the valve's normal flow direction). However, leak rate testing of the two valves in a steam line is frequently performed in a way that tends to open one of the valves; that is, one valve is pressurized below the poppet while the other is pressurized above the poppet, thereby affecting the valve closure force needed to obtain proper seat leakage characteristics. This practice is necessitated by the pressure limitations of currently available steam line plugs used during the tests. EPRI has initiated a project to develop plugs that would allow the LLRT pressure to be applied in the valve-closing direction for both valves in a single steam line (RP2073).

Field data on MSIV LLRT results indicate that stem packing leakage is another cause of valve failure to meet leakage criteria. Under RP1623-1 Stone & Webster Engineering Corp. conducted a study to identify the causes of stem packing leakage and to develop recommendations for improving packing performance. This study, reported in NP-2560, indicates that the use of graphite packing as a replacement for conventional asbestos packing can result in significant improvement in stem seal leakage performance.

Another promising practice noted in the Stone & Webster study is the use of live loading, in which a predetermined load is maintained on the stem packing by such means as Belleville springs to automatically compensate for relaxation and aging of the packing material (Figure 3). When used in conjunction with graphite packing, live loading is expected to extend the maintenance period of the stem seal to two years or more. The maintenance period for conventionally packed stem seals is about one year. The results of a test program conducted by Atomic Energy of Canada Ltd. led to its specification of the live-loading feature in all nuclear valves $2\frac{1}{2}$ in (6.35 cm) and larger.

A major portion of EPRI's Nuclear Power Division valve R&D effort continues to focus on improving BWR MSIV seat leakage performance. As noted above, RP2073 is addressing main steam line plugs for BWR application. Another project (RP1939) concerns the development of a tool and techniques for honing the valve body seating surface of MSIVs without removing the valve from the piping system. Performance criteria for the tool include adjustable positioning of its center of rotation, measurement and viewing capabilities, and remote control or programmable operation capabilities.

A project on the reapplication of hard-facing material to MSIVs was recently initiated (RP2186). First, the state of the art of hard-facing processes is being assessed. Then, the project will seek to develop equipment and techniques for the in situ reapplication of Stellite 21 (Cabot Corp.) onto the main body seat of MSIVs. The utility industry is expected to need this capability because of the depletion of seat facing materials by the periodic grinding and lapping required to meet LLRT criteria. The technology has significant application beyond MSIVs as well.

Current valve R&D projects that are not directly related to the MSIV problem are addressing on-line leak sealing (RP1328), advanced overpressure protection for PWR plants (RP2007), and alternative test media and methods for use in the set-point testing of safety valves (RP1811).

A project was recently approved to establish objectives and funding levels for future research on other key valves (RP2233). The project will include the ranking of valve problem areas on a cost-effectiveness basis and the general scoping of activities for effectively addressing each problem area. *Project Manager: Boyd Brooks*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1348-16	Technical Assessment of Biomass-Derived, Low-Btu Gas as a Fuel Source for Existing Utility Diesel Generating Units	5 months	43.1	Burns & McDonnell Engineering Co. *S. Kohan*
RP1459-2	Film: Texaco Gasification–Combined-Cycle Demonstration Plant	30 months	179.1	Bravura Films, Inc. *J. Janasik*
RP1657-2	Evaluation and Qualification of Ceramic Substrate Materials for Stationary Gas Turbine Catalytic Combustors	14 months	149.4	Engelhard Corp. *W. Bakker*
RP1996-3	Solano County Mod-2 Wind Turbine Evaluation	23 months	219.1	Pacific Gas and Electric Co. *F. Goodman*
RP2003-2	10-MW (e) Solar-Thermal Pilot Plant: Report on Lessons Learned and Project Documentation	7 months	149.6	Burns & McDonnell Engineering Co. *J. Bigger*
RP2029-10	Evaluation of Texaco Gas Cooling Costs for GCC Power Plants	18 months	471.2	Fluor Engineers and Constructors, Inc. *M. Gluckman*
RP2112-7	Synthetic Fuels Logistics	18 months	850.6	Radian Corp. *H. Schreiber*
RP2112-9	Synfuel Field Test—Industrial Hygiene	7 months	76.7	Tabershaw Occupational Medicine Associates *H. Schreiber*
RP2221-1	Performance Improvement for GCC Power Systems Using Low-Rank Coals	5 months	50.0	Energy Conversion Systems, Inc. *N. Holt*
Coal Combustion Systems				
RP982-29	Chiyoda Demonstration Test Plan	8 months	85.6	Bechtel Group, Inc. *T. Morasky*
RP1266-32	Feasibility of Using Rapid Freeze Plugs for Waterwall Tube Repairs	9 months	71.0	Babcock & Wilcox Co. *J. Dimmer*
RP1403-4	Development Plan for Advanced Pulverized-Coal Power Plants	17 months	252.8	Gilbert Associates, Inc. *A. Armor*
RP1609-2	Definition of Economic Benefit of Integrated Environmental Controls for Coal-Fired Power Plants	6 months	42.6	Black & Veatch Consulting Engineers *E. Cichanowicz*
RP1646-4	Empirical Evaluation of Integrated Environmental Control Configurations for Coal-Fired Power Plants	18 months	1168.3	Brown and Caldwell, Inc. *E. Cichanowicz*
RP1685-6	Evaluation of Site Closure–Land Reclamation Methods for Power Plant Disposal Sites	8 months	49.0	Michael Baker, Jr., Inc *D. Golden*
RP1855-2	Laser-Doppler Velocimeter Program, Phase 2	16 months	284.6	General Electric Co. *A. Armor*
RP1862-2	In-Service Rotor Crack Detection System	4 years	1320.9	General Electric Co. *A. Armor*
RP1895-10	Coal-Water Slurry Loop Tests	7 months	40.0	Adelphi Research Center, Inc. *R. Manfred*
RP2248-1	Investigation of FGD Chemical Process Problems	30 months	418.1	Radian Corp. *D. Stewart*
RP2248-4	FGD Equipment Sparing Practices	8 months	74.3	Black & Veatch Consulting Engineers *D. Stewart*
RP2250-1	FGD Damper Design and Operation	17 months	268.1	Black & Veatch Consulting Engineers *T. Morasky*
RP2256-1	Effects of Coal Quality on Power Plant Performance and Costs	1 year	200.0	Energy and Environmental Research Corp. *A. Mehta*
Electrical Systems				
RP1504-3	NGH Subsynchronous Resonance Damping Scheme	23 months	1217.4	Siemens-Allis Corp. *N. Hingorani*
RP2005-1	Lightning Transient Recorder Development	16 months	28.1	Macrodyne, Inc. *H. Songster*
Energy Analysis and Environment				
RP652-3	Sensitivity Analysis of Energy Conservation	4 months	53.9	Applied Energy Services, Inc. *S. Mukherjee*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP940-5	Analyses of London Mortality Data	3 months	35.4	H. Daniel Roth Associates *R. Wyzga*
RP2020-1	Selenium Speciation Techniques for Natural Waters and Sediments	25 months	61.7	Old Dominion University Research Foundation *J. Huckabee*
RP2020-2	Arsenic in Natural Waters and Sediments	25 months	103.1	Battelle, Pacific Northwest Laboratories *J. Huckabee*
RP2047-2	Transferability of Direct Load Control Experiment Results	4 months	285.2	Booz, Allen & Hamilton, Inc. *E. Beardsworth*
RP2159-2	Newer Approaches to Assessing Exposures in Air Pollution Epidemiology	4 months	34.9	Arthur D. Little, Inc. *C. Young*
RP2263-1	Thermal Discharge Standards Framework	1 year	134.9	SRI International *V. Niemeyer*
RP2264-1	Atmospheric Deposition of Sulfate During SURE	35 months	250.0	Yale University *R. Patterson*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1201-20	Concept Study: Distributed Logic Load Management Control Systems	22 months	64.1	Honeywell Technology Strategy Center *V. Rabl*
RP1276-13	Evaluation of DEUS Conceptual Design—Distillation Columns	16 months	340.0	Procon International, Inc. *D. Hu*
RP1967-5	Evaluation of Absorptive Coatings for Use With Material Processing Lasers	1 year	50.0	University of Southern California *J. Brushwood*
RP2033-15	Design Goals: Advanced Heat Pumps	11 months	100.0	U.S. Dept. of Commerce *J. Calm*
RP2034-1	Energy Use, Infiltration, and Indoor Air Quality in Tight, Well-Insulated Residences	26 months	694.2	Geomet Technologies, Inc. *A. Lannus* *R. Patterson*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP502-12	Verification of Turbine Reliability Technology	3 months	181.1	J. A. Jones Applied Research Co. *M. Kolar*
RP810-11	Soil-Structure Interaction Effects	9 months	969.2	Niagara Mohawk Power Corp. *K. Winkleblack*
RP814-6	DATATRAN Installation, Qualification, and Analysis	10 months	2S.4	Intermountain Technologies, Inc. *P. Bailey*
RP1557-6	Radionuclide Correlations in Low-Level Radwaste, Phase 1	3 months	76.7	EDS Nuclear, Inc. *M. Naughton*
RP1561-4	BWR Design Data and Transient Test Documentation at Grand Gulf	15 months	71.8	General Electric Co. *P. Bailey*
RP1731-3	Scaling Analysis of SRI Upgrade Test Facility for B&W System Design	5 months	37.6	Babcock & Wilcox Co. *J. Sursock*
RP1761-19	NODETRAN Mods to New Node—P	3 months	27.3	Systems Control, Inc. *W. Eich*
RP1932-32	Subscale Hydrogen Visualization Test	6 months	167.5	Acurex Corp. *J. Hosler*
RP1935-4	Evaluation of Low-Cobalt Alloys for Hard-Facing Applications in Nuclear Components	11 months	101.7	Westinghouse Electric Corp. *H. Ocken*
RP2054-1	Analytic Simulators Qualification Methodology	18 months	339.2	Babcock & Wilcox Co. *J. Sursock*
RP2120-2	Aerosol Transport Through Reactor Primary Coolant System	2 years	298.7	Battelle, Columbus Laboratories *M. Merilo*
RP2135-5	LWR Source Term Experiments	3 months	145.0	Argonne National Laboratory *R. Vogel*
RP2168-3	TMI-2 Equipment Survivability Methodology Study	6 months	98.2	Westinghouse Electric Corp. *G. Sliter*
RP2176-1	Pipe Rupture and Depressurization Experiments	18 months	1538.6	Wyle Laboratories *H. Tang* *R. Duffey*
RP2180-6	Fracture Toughness of RPV Steel	7 months	158.8	General Electric Co. *T. Marston*
RP2189-1	Qualification of Mechanical Components	18 months	306.6	Mollerus Engineering Corp. *C. Chan*
RP2225-1	Feasibility Study: Large-Scale Seismic Test	3 months	46.1	Robert L. Cloud Associates, Inc. *H. Tang*
RP2227-2	Development of a Simplified Piping Design Handbook	1 year	65.0	Echo Energy Consultants, Inc. *R. Nickell*
RP2240-5	Feasibility of Scaling Ferritic Spent-Fuel Storage/Shipping Casks	2 months	44.5	Fracture Control Corp. *R. Nickell*
RP2288-1	Reactor Safety Study: PWR Source Term and Risk Update Program	17 months	548.3	Science Applications, Inc. *I. Wall*
RP2294-1	Evaluation of Diagnostic Training for Nuclear Power Plant Personnel	11 months	98.3	Search Technology, Inc. *J. O'Brien*

R&D Staff

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2278-1	Simultaneous Chromizing-Aluminizing of Steels	25 months	103.6	Ohio State University *J. Stringer*

New Technical Reports

Each issue of the *Journal* includes summaries of EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others in the United States, Mexico, and Canada pay the listed price. Research Reports Center will send a catalog and complete price list (including foreign prices) on request.

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

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

ADVANCED POWER SYSTEMS

Moving-Bed Gasification–Combined-Cycle Control Study: Oxygen-Blown, Slagging Ash Operation

AP-1740 Final Report (RP914-1), Vol 2; $12.00

This volume details the second part of a computer simulation analysis of process dynamics and control for advanced gasification–combined-cycle plants. It addresses plants based on moving-bed gasifiers with slagging operation. The contractor is General Electric Co. *EPRI Project Manager: G. H. Quentin*

Photovoltaic Cell and Module Status Assessment

AP-2473 Final Report (RP1975-1); Vol. 1, $12.00; Vol. 2, $16.50

This report presents the results of a project to document the current status of photovoltaic cell and module technology. It is intended to serve as an aid in assessing new developments. Volume 1 provides an overview of cell and module status. Volume 2 presents a series of in-depth appendixes that cover the basics of photovoltaic technology. The contractor is Research Triangle Institute. *EPRI Project Manager: R. W. Taylor*

Combustion and Gasification Characteristics of Chars From Four Commercially Significant Coals of Different Rank

AP-2601 Final Report (RP1654-6); $15.00

Bench-scale tests were conducted in a drop-tube furnace system to determine the chemical reaction kinetics of four size-graded coal chars: Pittsburgh No. 8 seam hvAb, Illinois No. 6 seam hvCb, Wyoming subbituminous C, and Texas lignite A. Other tests determined the physicochemical properties of the coals and chars. Results show that lower-rank coal chars are more reactive than higher-rank coal chars and that char combustion reactions are much faster than corresponding gasification reactions. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: G. H. Quentin*

Characterization of Thermal Decomposition of Coal in Experimental Reactors

AP-2602 Final Report (RP1654-7); $12.00

This report presents a comparison of theoretical and experimental studies of coal pyrolysis in a laminar entrained-flow reactor at temperatures up to 1500°C. It discusses the use of a model of coal pyrolysis that has been successful in simulating lower-temperature experiments. It also describes experiments performed in a drop-tube furnace system and the analysis of the chars by Fourier transform infrared spectroscopy and optical microscopy. The contractor is Advanced Fuel Research, Inc. *EPRI Project Manager: G. H. Quentin*

EDS Coal Liquefaction Process Development

AP-2604 Annual Report (RP778); $43.50

This is the fifth annual report on Exxon Donor Solvent (EDS) process development and covers the period from July 1, 1980, to June 30, 1981. The shakedown of the EDS coal liquefaction pilot plant at Baytown, Texas, is discussed, and the results of the first test programs are presented. Modifications performed after the initial operation are also described. The contractor is Exxon Research and Engineering Co. *EPRI Project Manager: N. H. Hertz*

H-Coal PDU Tests on Wyodak Coal

AP-2623 Final Report (RP238-3); $24.00

This report describes an experimantal and analytic investigation of the processing of Wyoming subbituminous coal from the Wyodak mine in the 3-t/d H-Coal process development unit. The contractor is Hydrocarbon Research, Inc. *EPRI Project Manager: N. C. Stewart*

H-Coal PDU Tests on Kentucky No. 11 Coal

AP-2624 Final Report (RP238-3); $21.00

This report describes an experimental and analytic investigation of the processing of Kentucky No. 11 coal in the 3-t/d H-Coal process development unit. The work was part of a project to ready a 250-t/d pilot plant for operation. The contractor is Hydrocarbon Research, Inc. *EPRI Project Manager: N. C. Stewart*

Assessment of Distributed Photovoltaic Electric Power Systems

AP-2687-SY Summary Report (RP1192-1); $9.00

This report summarizes work to develop and test (through case studies) a methodology for assessing the potential impacts of distributed photovoltaic (PV) systems on electric utility systems. The impacts of PV systems on utility system operations, generation mix, and subtransmission and distribution systems were assessed. Also, the economic potential of distributed PV systems was investigated for utility ownership and for customer ownership. The contractor is JBF Scientific Corp. *EPRI Project Managers: F. R. Goodman, Jr., and E. A. DeMeo*

ELECTRICAL SYSTEMS

Human Factors Review of Electric Power Dispatch Control Centers

EL-1960 Final Report (RP1354-1); Vol. 3, $10.50; Vol. 4, $15.00

This six-volume report details a three-part study of the dispatch control center environment in which a power system dispatching team is expected to perform its duties with a minimum of errors. Volumes 3 and 4 identify the needs for, and the uses of, power system information by a system operator in conditions ranging from normal to degraded operation. Volume 3 summarizes operator information needs, and Volume 4 presents them in more detail. The contractor is Stagg Systems, Inc., for Lockheed Missiles & Space Co., Inc. *EPRI Project Manager: C. J. Frank*

Thermal Stability of Soils Adjacent to Underground Transmission Power Cables

EL-2595 Final Report (RP7883); $13.50

This report describes work on the performance of soils surrounding power cables, the transmission of heat from the cables through the soils, and soil stability as a function of relevant parameters. An analytic model that mathematically simulates heat transfer and moisture migration in soil is detailed. Tests made with thermal probes embedded in reproducible soil samples and experimental measurements made in a tank with full-sized cables as heat sources are discussed. The contractor is the Georgia Institute of Technology. *EPRI Project Manager: R. W. Samm*

Study of Turbine Generator Shaft Parameters From the Viewpoint of Subsynchronous Resonance

EL-2614 Final Report (TPS81-794); $18.00

This report documents an investigation of the susceptibility of turbine generators to subsynchronous resonance (SSR) problems as a result of shaft, network, and load characteristics. Electrical damping characteristics of generators were calculated over a wide range of network conditions, and the data were used with several different typical shaft characteristics to evaluate the impact of SSR. The contractor is Power Technologies, Inc. *EPRI Project Manager: D. K. Sharma*

Improved Transformer Oil Pump

EL-2619 Final Report (RP1797-1); $16.50

This report describes the design of a prototype transformer oil pump of improved reliability that would not contaminate a transformer with conductive debris during normal operation or in the event of pump failure. The chosen design, based on the rotating-casing pump principle, is described in detail, and full manufacturing drewings and a parts list are presented. The contractor is Mechanical Technology, Inc. *EPRI Project Managers: D. K. Sharma and J. C. White*

Gases Superior to SF_6 for Insulation and Interruption

EL-2620 Final Report (RP847-1); $31.50

This report describes experimental and theoretical studies of the insulation and interruption properties of gases and gas mixtures of potential use as replacements for SF_6 in compressed-gas-insulated transmission equipment and interrupters. The report contains detailed quantitative data on the electric strength, interruption properties, vapor pressure, carbonization behavior, diffusion rates, thermal aging behavior, toxicity, and other properties of the gases and gas mixtures. The contractors are Westinghouse Research and Development Center and E. I. du Pont de Nemours & Co., Inc. *Project Managers: B. S. Bernstein and Edward Norton*

Basic Research on Transformer Life Characteristics

EL-2622 Final Report (RP1289-2); $21.00

This report describes the preparation and testing of a series of insuleted conductor model coils and a group of subassembly model transformers designed to represent typical 50-MVA transformer windings. Organized to evaluate the significant factors affecting transformer life, the project covered gas evolution during thermal aging of insulation and thermal, mechanical, and electric stresses over time. Scaling factors are discussed, and recommendations for future life tests are presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: B. S. Bernstein*

Fiber Composite Retaining Rings for Turbine-Driven Generators

EL-2674 Final Report (RP1474-1); Vol. 1, $16.50; Vol. 2, $15.00; Vol. 3, $13.50; Vol. 4, $19.50

This report discusses the development of a carbon fiber composite material suitable for the manufacture of retaining rings. The fabrication and testing of such a ring are also addressed. Volume 1 covers material development, and Volume 2, the fabrication of the retaining ring. Volume 3 discusses the testing procedures, and Volume 4 provides conceptual design alternatives for solving the problems of ring attachment and circulating currents. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: D. K. Sharma*

Far-Infrared Laser Scanner for High-Voltage Cable Inspection

EL-2675 Final Report (RP794-3); $10.50

This report details the third phase of the development of a far-infrared laser scanner for the on-line factory inspection of the solid-dielectric insulation of high-voltage cables for use in underground distribution systems. In this phase a laboratory model of the instrument was built and successfully tested. The contractor is United Technologies Research Center. *EPRI Project Manager: Joseph Porter*

ENERGY ANALYSIS AND ENVIRONMENT

Prevention of Golden Eagle Electrocution

EA-2680 Final Report (RP1002); $10.50

Contributing factors in eagle electrocutions were investigated, along with possible methods of mitigating the problem. Electrocutions were documented in six western states by examining carcasses found below power lines. The report notes that more eagles were electrocuted in cottontail rabbit habitats than in other areas. Measures to lower the incidence of electrocution—routing lines around preferred prey habitats, locating power poles in topographically low areas, and insulating pole conductors—are described. The contractor is Brigham Young University. *EPRI Project Managers: J. W. Huckabee and R. A. Goldstein*

Biochemical Genetics of Largemouth Bass

EA-2688 Final Report (RP1063-1); $22.50

A biochemical study of the genes of 90 populations of largemouth bass was conducted to evaluate the usefulness of biochemical genetic techniques in describing responses of fish populations to thermal regimes. Vertical starch gel electrophoresis and histochemical staining techniques were used to determine phenotypes at 28 enzyme loci for 20 individuals per population. Allele frequencies at each locus, the mean number of alleles at each locus, the average number of polymorphic loci, and the mean level of heterozygosity are addressed. The contractors are the Illinois Natural History Survey and the University of Illinois. *EPRI Project Manager: R. W. Brocksen*

Effects of Chlorine on Marine Benthos

EA-2696 Final Report (RP1224-4); $12.00

This report presents the results of research to develop and test an open-microcosm methodology for investigating the effects of chlorination on marine benthic communities. Measurements of the rate and extent of colonization are given, and the affects of chlorination and other experimental parameters are discussed. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. W. Huckabee*

Methods for Analyzing the Market Penetration of End-Use Technologies: Guide for Utility Planners

EA-2702 Final Report (RP2045-2); $15.00

This report presents a survey of various methods for estimating market saturation of end-use technologies, with emphasis on electric utility planning needs. Each method is explained in terms of its theoretical basis, data requirements, variants, relationship to other methods, strengths and weaknesses, ability to incorporate uncertainty, and suitability. A telephone survey on current business practice is described, and criteria for method selection are put forth. The contractor is Resource Planning Associates, Inc. *EPRI Project Manager: Edward Beardsworth*

ENERGY MANAGEMENT AND UTILIZATION

Sulfur-Tolerant Fuel Processors for Fuel Cell Power Plants

EM-2686 Final Report (RP1041-4); $13.50

The development of fuel processors that could use middle-distillate fuels in dispersed fuel cell generators is described. The report details the program plan; the test stand and procedures; the results for metal oxide, noble metal, and Toyo Engineering Corp. catalysts; and the kinetic analysis of fuel conversion data. The results from this project and a related effort by Kinetics Technology International Corp. confirm the technical feasibility of the hybrid fuel processor for using high-sulfur middle-distillate fuels in dispersed fuel cells. The contractor is United Technologies Corp. *EPRI Project Manager: E. A. Gillis*

Assessment of Utility Impact of Electrification in the U.S. Chemical Industry

EM-2700 Final Report (RP1086-11); $13.50

This report presents an assessment of the prospects for large-scale implementation of electro-organic synthesis processes in the chemical industry and the impact such processes would have on the utility industry. To determine potential electricity demand, candidate processes were screened against certain criteria, including projections of damand for the chemical (and thus the need for new plants) and the merits of the electrochemical processes versus conventional processes. The contractor is SRI International. *EPRI Project Manager: B. R. Mehta*

NUCLEAR POWER

Reactor Transient Tests at ANO-2

NP-1709 Final Report (RP1385-1); $15.00

This report documents a series of reactor transient tests performed at Arkansas Nuclear One, Unit 2, for use in qualifying reactor system transient analysis computer codes. Four tests were conducted: complete loss of forced primary coolant flow, full-length control element assembly (CEA) drop, part-length CEA drop, and turbine trip. The report describes the tests and discusses their use in providing a basis for increased industry confidence in the ability of computer codes to predict the course of various operating transients. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: J. A. Naser and R. N. Whitesel*

Properties of Colloidal Corrosion Products and Their Effects on Nuclear Plants

NP-2606 Final Report (RP966-1); Vol. 1, $9.00; Vol. 2, $19.50

This report describes a laboratory-scale effort to characterize the properties of corrosion-product particulate oxides, such as magnetite and hematite, in water heat transfer loops in LWRs. Volume 1 is an executive summary, and Volume 2 contains the detailed results. The contractor is Clarkson College of Technology. *EPRI Project Manager: T. O. Passell*

Test of Job Performance Aids for Power Plants

NP-2676 Final Report (RP1396-1); $16.50

This report describes a study of the potential effectiveness of using job performanca aids (JPAs) in selected applications in the nuclear power industry. Sample JPAs developed for control room operations, maintenance, plant operations, instrumentation and control, health physics, and quality assurance tasks are detailed. Criteria for judging JPA benefits in specific situations are presented, as well as guidelines for the development of JPAs that meet industry requirements and constraints. The contractor is Kinton, Inc. *EPRI Project Manager: H. L. Parris*

Evaluation of Cobalt Sources in Westinghouse-Designed Three- and Four-Loop Plants
NP-2681 Final Report (RP1784-3); $13.50

This report identifies sources of cobalt in two typical Westinghouse-designed three- and four-loop LWR power plants. Materials determined to have a pathway for contributing cobalt to the primary coolant system were inventoried. A detailed analysis of the materials is given, classifying them by alloy identification, cobalt weight percentage, and associated surface area. On the basis of a cost-benefit analysis, recommendations are made concerning cobalt reduction options. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: M. D. Naughton*

Thermal-Hydraulic Analysis of the Westinghouse Model 51 Steam Generator
NP-2683 Final Report (RPS130-1); $24.00

The computer code THIRST was used to perform a thermal-hydraulic analysis of the Westinghouse Model 51 recirculating steam generator for operating conditions at 100%, 50%, and 20% of nominal power. The methodology, assumptions, and empirical correlations used in THIRST ara discussed, and quantitative code results are given for each power level, including the parameters that characterize overall unit performance and complete local details of the flow field. The contractor is Atomic Energy of Canada Ltd. *EPRI Project Manager: D. A. Steininger*

Cobalt Source Identification Program
NP-2685 Final Report (RP1784-1); $10.50

This report identifies the major potential sources of cobalt-58 and cobalt-60 in an operating Combustion Engineering PWR—that is, materials determined to have a pathway for contributing cobalt to the primary coolant. The report summarizes the chemistry environment and conditions for each material and presents calculated cobalt release rates. Design modifications and material replacement options for eliminating or reducing the major cobalt sources are assessed. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: M. D. Naughton*

Tests of Types 51A and 51M Steam Generators at Bugey-4 and Tricastin-1 Nuclear Power Plants
NP-2689 Final Report (RPS154-1); $16.50

This report presents thermal-hydraulic and chemical sampling data obtained at various power levels from special instrumentation on Electricité de France's operating steam generators at Bugey-4 and Tricastin-1. The data include downcomer flow rates, shell temperatures, and temperatures and chemical concentrations near the secondary surface of tubesheets. These data are useful for qualifying thermal-hydraulic computer codes. The contractor is Electricité de France. *EPRI Project Manager: C. L. Williams*

Evaluation of Nonchemical Decontamination Techniques for Use on Reactor Coolant Systems
NP-2690 Topical Report (RP2012-2); $18.00

This report presents an examination of 17 nonchemical decontamination methods, citing development history, prior applications, and specific advantages and disadvantages. Aimed at creating a body of information that will be useful to the utility industry in any postaccident situation, the project characterized and evaluated decontamination techniques that could be applied to the cleaning of fuel debris and corrosion products from reactor coolant systems and components. The contractor is Quadrex Corp. *EPRI Project Manager: L. E. Anderson*

Evaluation of Abrasive Grit–High-Pressure Water Decontamination
NP-2691 Final Report (RP2012-4); $9.00

This report details an abrasive grit–high-pressure water technique developed primarily for the decontamination of steam generator channel heads. It presents a description of the system; summaries of field experience to date; general guidelines, criteria, and pertinent parameters that must be considered when applying the decontamination method; and a general assessment of the applicability of the method to various components and systems. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: L. E. Anderson*

Control of Containment Air Temperature: Industry Survey and Insulation Test
NP-2694 Final Report (RP1730-1); $15.00

The causes of high air temperatures in nuclear power plant containment buildings were investigated. This report presents an analysis of causative factors, such as exposed hot surfaces unaccounted for in design, compromises in insulation installation, higher-than-expected latent heat loads, and inadequate cooling-air circulation. A review of current engineering practices in the design of containment building thermal environmental control systems is given, and the testing of five types of commercial insulation is discussed. The contractor is Dynatech R/D Co. *EPRI Project Manager: T. M. Law*

Salem Unit 1 Denting Mitigation Program: Implementation of Improved Oxygen, Chloride, and Copper Control
NP-2703 Final Report (RPS132-5); $13.50

This report discusses the results obtained in the Salem Unit 1 denting mitigation program. A review of the unit's chemistry operations during fuel cycles 1 and 2 is presented. Secondary-side chemistry control and monitoring methods for the third fuel cycla are discussed, and the findings of the steady-state, high-power chemistry monitoring effort are addressed. Hydrogen monitoring and eddy-current inspection results are included. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Coit*

PWR Secondary Water Chemistry Guidelines
NP-2704-SR Special Report; $12.00

This report presents a justification for water chemistry control parameters and describes available analytic methods, data management and surveillance, and the management philosophy required to successfully implement the guidelines. The guidelines presented should aid the electric utility industry in the management of PWR secondary water chemistry to minimize localized corrosion in steam generators and turbines. *EPRI Project Manager: S. J. Green*

Structural Mechanics Progress in 1981
NP-2705-SR Special Report; $18.00

This report reviews the significant progress made in 1981 in the Structural Mechanics Program and discusses the interrelationships of the projects. The program now has 14 research topics with more than 40 separate contracts. An up-to-date account of structural mechanics issues and a discussion of progress toward resolving them are provided. Program plans are also included. *EPRI Project Manager: T. U. Marston*

Secondary Water Chemistry Control at St. Lucie No. 1
NP-2706 Topical Report (RPS170-1); $12.00

The plant design characteristics, operating philosophy, chemistry history, and damage history of Florida Power & Light Co.'s St. Lucie Unit 1 are reviewed. This review provides insight into the factors that may have led to the early onset of steam generator corrosion damage. The report documents the marked improvement in water chemistry performance and the reduction in corrosion damage progression achieved by major condenser modifications. The contractor is NWT Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Prevention of Wear Problems in PWR Steam Generators: Annotated Bibliography
NP-2711 Final Report (RPS145-1); $9.00

This report documents a literature survey of specific waar mechanisms, focusing on studias that involve materials and/or geometries and operating conditions related to PWR steam generators. It provides a state-of-the-art compilation of available literature on solid-particle impact erosion, liquid-droplet impact erosion, cavitation erosion, and fretting. The contractor is Hydronautics, Inc. *EPRI Project Manager: C. L. Williams*

R Curve Characterization of Low-Strength Structural Steels
NP-2715 Final Report (RP2055-7); $10.50

The results of a six-month project to generate fracture toughness data on three low-strength structural steels are described. The report discusses the relationships of fracture toughness, Charpy energy, drop weight, and dynamic tear test results and describes the fuel fracture toughness transition curve for each material tested. The results indicate that for the materials evaluated, nil ductility transition temperature is not a reliable indication of the static fracture toughness transition temperature. The contractor is Materials Engineering Associates, Inc. *EPRI Project Manager: T. U. Marston*

Characterization of the Contamination in the TMI-2 Reactor Coolant System
NP-2722 Final Report (RP2012-1); $10.50

This report describes an effort to characterize the contamination on the primary-system surfaces of TMI-2 in support of decontamination process selection and planning. The identification of methods for analyzing fission-product and fuel-debris dispersion in a severe reactor accident is addressed, and the use of these methods to characterize the contamination in the TMI-2 reactor coolant system is discussed. Conclusions and recommendations are presented. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: L. E. Anderson*

Index to 1982 EPRI Journal

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

NONPROFIT ORGANIZATION
U.S. POSTAGE
PAID
PERMIT NUMBER 7577
SAN FRANCISCO, CALIFORNIA

EPRI

ADDRESS CORRECTION REQUESTED