

Global Realignment in Equipment Supply

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Cover: International mergers and business alliances
have left five major players in the power equipment
supply market: the United States, Japan, West
Germany, Sweden, and Switzerland.

Equipment Technology and Global Competition

For the science and technology arm of the electric utility industry, changes in the array of power equipment manufacturers supplying the U.S. market have important implications. Traditionally, American manufacturers have been major partners of EPRI in development activities, both because they were more familiar with the U.S. utility market than were foreign suppliers and because they were undisputed technological leaders in virtually all areas of power equipment.

Recent major retrenchments by American manufacturers, fierce international competition, milestone mergers between European suppliers, and new alliances between foreign and domestic firms have begun to change that picture. For EPRI and its members, the emerging globalization of equipment supply poses new questions about sourcing—both of hardware and of R&D. Utilities are increasingly shopping for the best package of price, quality, and service from suppliers, regardless of national origin or location of manufacture. In some equipment areas, there are now fewer suppliers competing on bids; the hope is that those remaining are committed to excellence and innovation.

Our job at EPRI remains one of ensuring that our member utilities and electricity consumers have available the best science and technology to provide electricity-based services effectively. But with the movement of manufacturing and associated R&D overseas, some U.S. jobs—consumers' jobs—could suffer, and the U.S. position as technological leader could erode.

For EPRI, the changes mean we must find ways to use our leverage to strengthen U.S. scientific and technical capabilities in this field. We will continue to work closely with traditional domestic suppliers in those equipment areas in which they remain the technology leaders and innovators. We must also look for budding entrepreneurs with capability and ideas. But when we find that the leading edge or the greatest potential for advancing technology lies offshore, we need to flexibly broker utility R&D funding for the maximum return. The globalization of technology means broader horizons in the search for innovation.

This month's cover story reports on the timely remarks of key insiders at a meeting earlier this year of our Advisory Council, as well as some thoughts and reflections of Council members and EPRI management. The role of electrical equipment producers in the technological future of the utility industry will continue to pose strategic challenges for EPRI in the months and years ahead.



A handwritten signature in cursive script that reads "Milton Klein".

Milton Klein, Vice President
Industry Relations and Information Services

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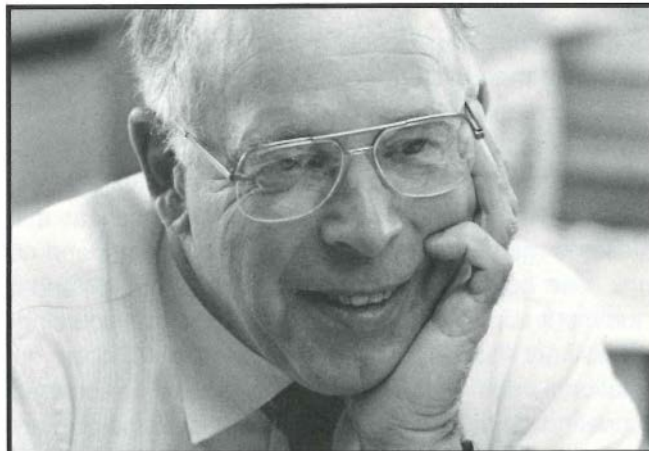
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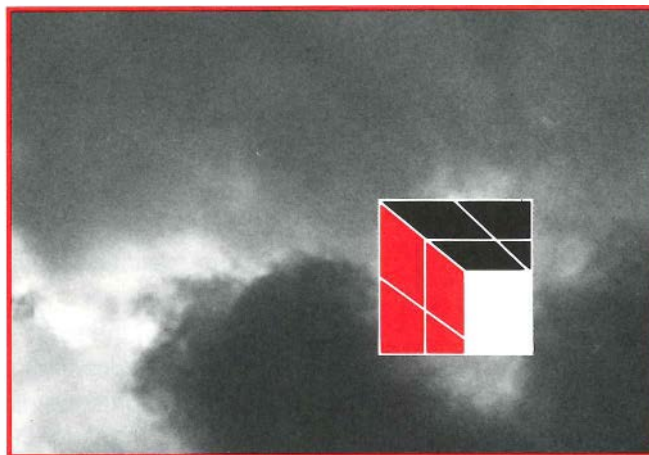
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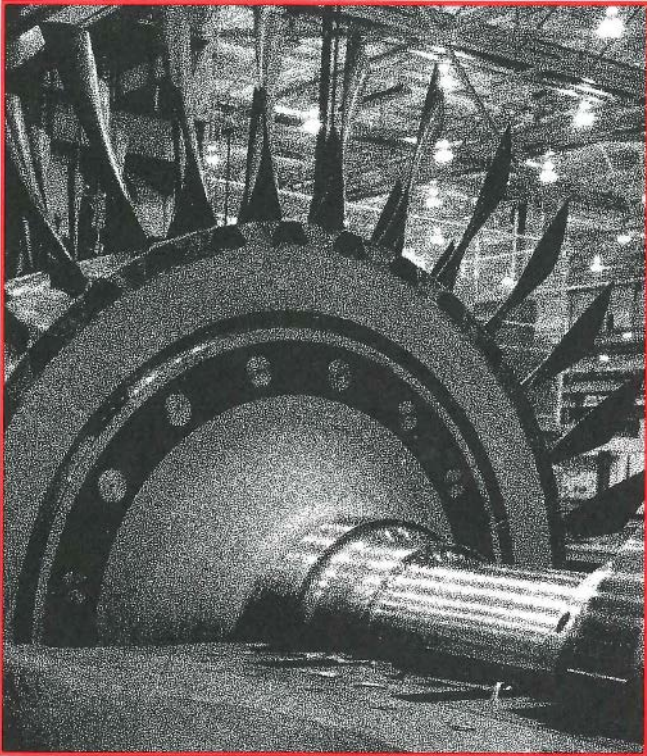
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Leveraged by a spate of international mergers, western Europe and Japan have mounted an aggressive push for key pieces of the global market in generation and transmission equipment. U.S. utilities are finding it difficult to resist the quality, prices, and commitment to service offered by these new conglomerates.

THE RISE of INTERNATIONAL SUPPLIERS

As electric service took root and began to spark a second industrial revolution around the turn of the century, first in the United States, then in Europe, and later in Japan, manufacturers of heavy electrical equipment emerged to supply their domestic markets. For the most part, American utilities bought their equipment from American suppliers, German utilities from German suppliers, Japanese utilities from Japanese suppliers, and so on. The same was largely true of electrical products for the commercial, consumer, and industrial markets.

Although there developed many intercorporate agreements and cross-licenses (both public and clandestine) among the major manufacturers around the world, booming domestic markets with steady growth in sales kept them largely preoccupied with their home turfs. Among American manufacturers, at least, the good times helped pay for major R&D programs that sustained a strong technological edge for many years and formed the basis for advances in utility systems as they expanded. The historical relationships between utilities and equipment manufacturers in the United States, Europe, and Japan are nearly as deep and rich as the history of modern technology itself.

Today the realities of the heavy electrical equipment market are quite different, with important implications both for utilities and for EPRI. The lines between domestic and international markets have blurred as technology and communications have rendered the global village a global economy.

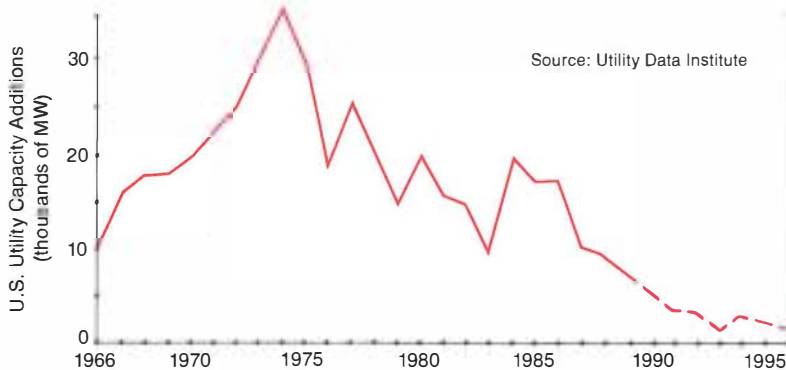
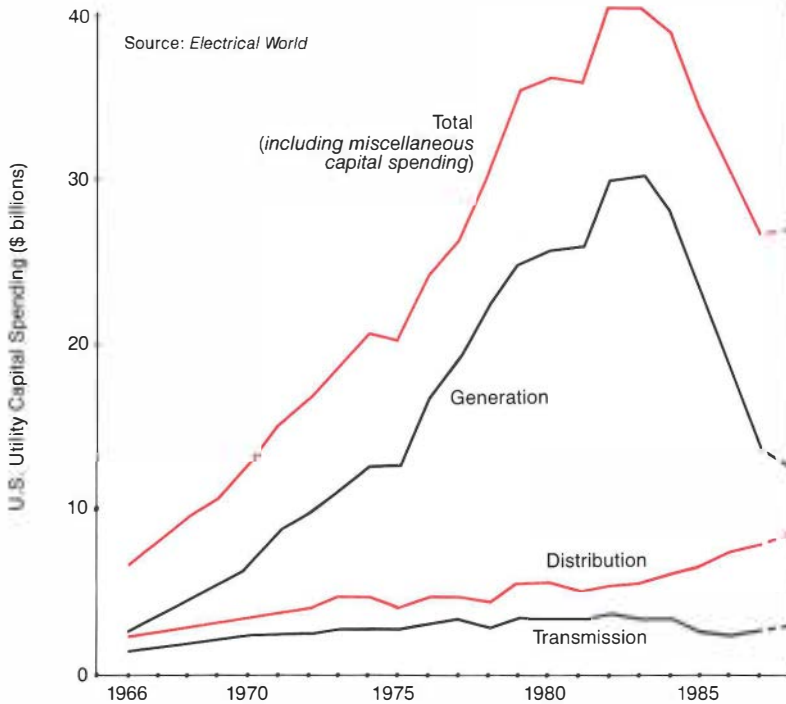
Firms such as General Electric and Westinghouse make and market utility generation and transmission equipment around the world, although it is a shrinking and increasingly less profitable segment of their highly diverse business interests. Power plant or system components that undergo final assembly in Pennsylvania or Florida may contain components from many different companies and countries. Some items are fully made abroad for sale under a domestic label. Other items, such as high-voltage circuit breakers, are no longer produced by domestic manufacturers. The leading edge of technology in certain equipment areas is held by foreign-based international firms eager to increase their inroads into the huge but stagnant American utility market.

Utilities that once preferred a "buy American" approach to procurement now openly seek the best combination of technology, price, and service regardless of national origin. The change reflects hard-nosed efforts to lower costs and remain competitive. Linger- ing concerns about the availability of spare parts in times of international crisis and about the impact on the domestic economy of factory closings when jobs move overseas, however, keep the subject a politically sensitive one. American equipment suppliers, meanwhile, complain of the lack of a level playing field in the global stadium: the home markets of their increasingly powerful European and Japanese competitors are not open to them.

Perceptions of a diminishing role for U.S. electrical equipment suppliers in

A Smaller Pie for Utility Equipment Vendors

Spending by American utilities for new plants and equipment has been in overall decline since 1982–1983, when a major expansion wave that began in the 1970s drew to a close. This year, spending for transmission and distribution is expected to rise, while budgets for generating plants and equipment continue to fall. But even at this year's forecasted total capital spending of over \$26 billion, the United States is still the largest single national market for utility power equipment. Figures are in current-year dollars, so the incline of the graph is exaggerated by inflation; figures for 1988 are prospective.



Slowdown in New Capacity Growth

The yearly addition of new capacity is down sharply from the major expansion period of the 1970s. This is reflected in utilities' reduced capital spending in the last five to six years. Continuing decline in new capacity has raised widespread concern over the adequacy of power supplies in the 1990s. Forecasts indicate a continuing downward trend through 1995.

domestic and world markets, as well as the implications of their admittedly drastic cutbacks in recent years in R&D for the utility industry, have been much on the minds of EPRI senior management and counselors. This issue was seemingly brought to a head in late 1987 with the merger of Asea of Sweden and Brown Boveri of Switzerland into the world's largest electrotechnical concern, Asea Brown Boveri.

The merger was followed with the announcement in April 1988 of an agreement between Asea Brown Boveri and Westinghouse for joint ventures in power generation and transmission and distribution. According to *The Wall Street Journal*, the move could lead to Westinghouse's exit from the T&D business by 1992. The power industry remains abuzz about what to make of it all and what may yet come.

Across the great divide

The news of planned combined operations between Westinghouse and Asea Brown Boveri in North American and selected world markets came as stunning confirmation of a picture painted by three speakers before EPRI's Advisory Council last April. An executive of the country's largest utility predicted that international suppliers would be a growing presence in the U.S. electrical equipment market, saying American utilities are responding to better quality, attractive prices, and a great commitment to service by the foreign firms. The head of General Electric's industry sales outlined the painful changes and signs of a turnaround at the world's former top equipment supplier (before the merger of Asea and Brown Boveri). And an official in the Office of the U.S. Trade Representative recounted government efforts to force an opening of western Europe to U.S. equipment suppliers as the dozen member nations of the European Community move toward becoming a single integrated market by 1992.

Gone are the days when American utilities bought electrical equipment almost exclusively from American manufacturers, said Donald Brand, senior vice president and general manager for engineering and construction at Pacific Gas and Electric. Now, under intense cost pressures, "American utilities willingly look beyond our traditional sup-

pliers for the best combination of price, quality, and service."

Over the last decade, as the market for big-ticket equipment items (turbines, generators, large transformers) contracted and utilities grew more cost-conscious, U.S. suppliers responded in several ways, according to Brand. They turned more to offshore sources for raw

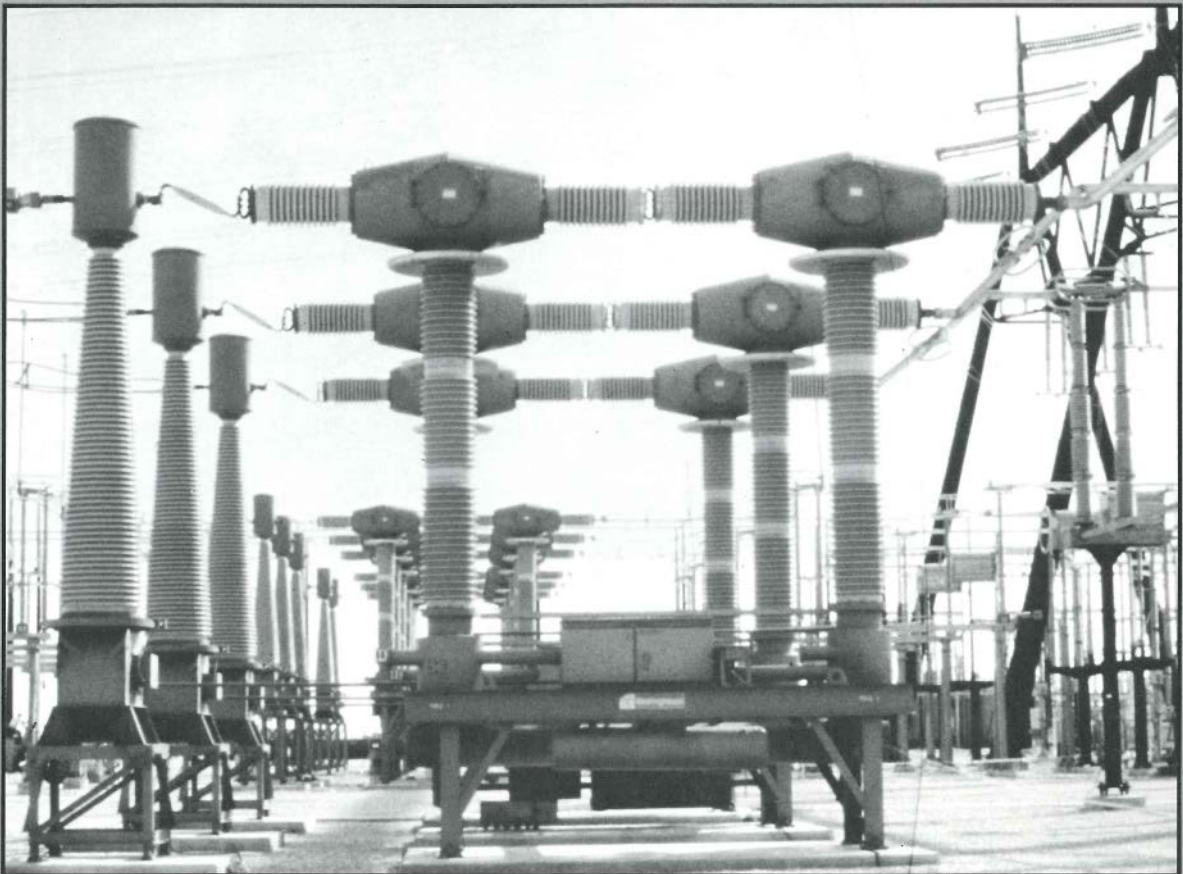
materials, components, even finished products. Many chose joint ventures with foreign companies. Brand cited those of GE with Hitachi and Westinghouse with Mitsubishi in high-voltage circuit breakers. The Japanese make the equipment for assembly and distribution in the United States by their state-side partners. Similarly, most large

UTILITY EQUIPMENT SUPPLIERS: THE CHANGING LINEUP

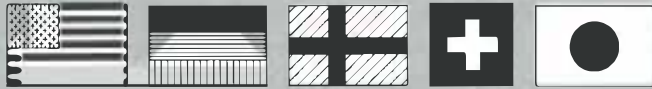
Extra-High-Voltage Circuit Breakers



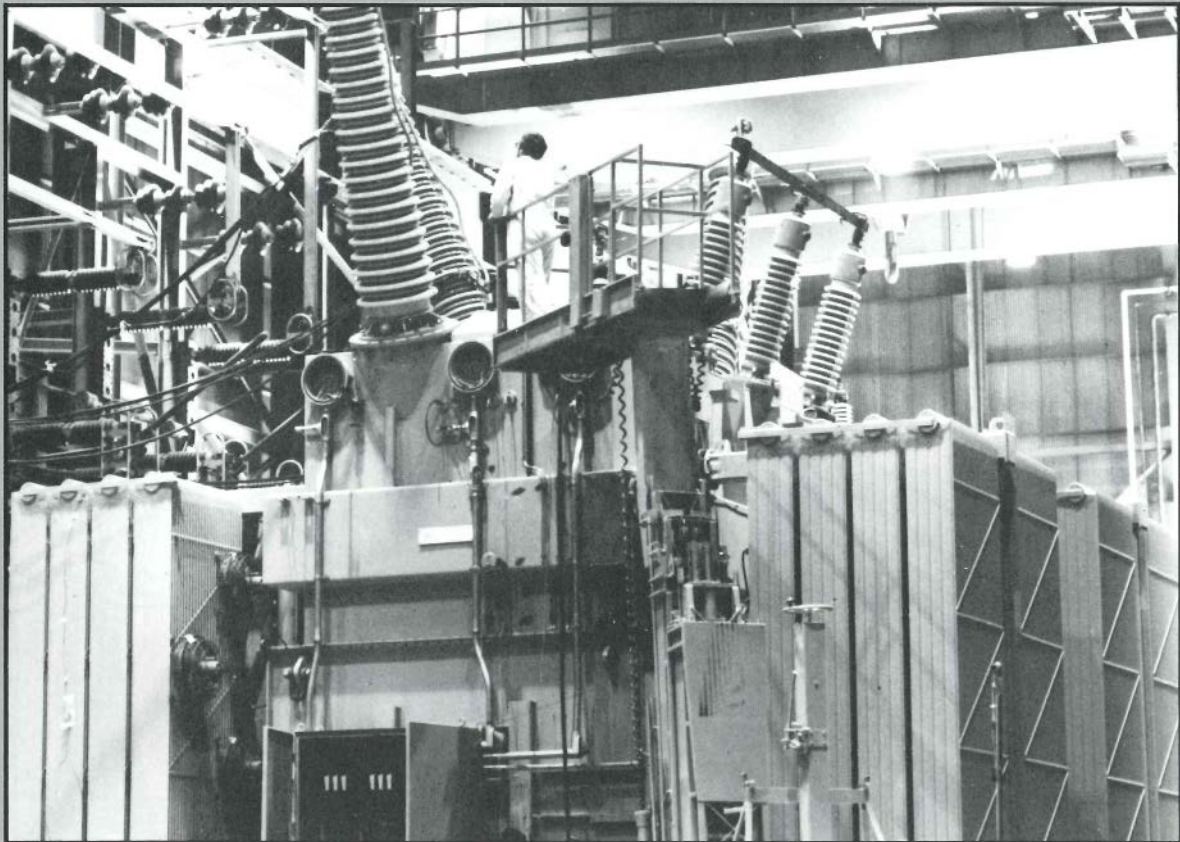
Ten years ago, four American suppliers of utility power equipment manufactured EHV circuit breakers in the United States; today, none does. General Electric sells breakers made in Japan by Hitachi, and Westinghouse markets Mitsubishi-made models. The only domestic producers are foreign suppliers serving the U.S. market—Siemens of West Germany and Asea Brown Boveri, based in Switzerland, both sell breakers made in U.S. factories.



Large Power Transformers



As a result of antidumping charges in the late 1960s and early 1970s, Japanese and most European suppliers withdrew from the U.S. market. In 1987 General Electric sold its business to Westinghouse, leaving Westinghouse and the McGraw Edison division of Cooper Industries as the only domestic suppliers. Two foreign-based suppliers—Asea (which manufactures units in the United States) and Brown Boveri—merged in 1987. Siemens and Hitachi both sell units here that are manufactured overseas; for the most part, Japanese suppliers still are not active in the domestic market.



Westinghouse combustion turbines are now made by Mitsubishi. (Westinghouse's association with Mitsubishi companies dates back to 1919.)

In other cases, Brand noted, American suppliers weighed the cost and market trends in certain equipment areas and chose to restructure, reduce,

or eliminate capabilities. Both GE and Westinghouse closed long-established steam turbine generator factories in 1987, transferring equipment and people and consolidating operations. Less than a year earlier, GE had shut down factories and abandoned the large power transformer business altogether.

"Increased competition, cost cutting, and lower electric demand growth would have hit the domestic equipment suppliers hard under any circumstances," said Brand. But in contrast to the domestic firms, "offshore suppliers took the utilities' call for cost reductions as a signal to expand." By coupling

quality products with attractive pricing and aggressive marketing, "they could expand right into the core of the American market."

Brand noted that the first announced goal of the merged Asea Brown Boveri was increased penetration of the U.S. market. In late 1986 the last major U.S.-owned hydroelectric turbine maker, Allis-Chalmers, was acquired by the German concern J. M. Voith. Switzerland's Sulzer Brothers, a manufacturer of large pumps and other gear, has announced plans to complete its acquisition of Bingham International, a leading American manufacturer of feedwater pumps.

Brand said that foreign firms are buying U.S. equipment manufacturers for "better access to our markets and to our highly skilled work force, technology, and research and development," as well as for the substantial savings from making more of their products here. Moreover, the recent depreciation of the dollar makes U.S. companies attractive and affordable buy-out targets. While some analysts believe that factor alone could trigger a resurgence of U.S.-based manufacturing, Brand said that in the near term, a revival "is more likely to result from a growing international presence in the United States." Foreign suppliers are determined to stick around. "They have an ongoing

commitment to meet our equipment and service needs."

Utilities are responding positively, said Brand. In 1974 less than 3% of turbines, generators, and transformers purchased were imported. In 1984 nearly 10% of major equipment came from offshore. In 1987 transformer imports topped 14% and turbines 28%, according to Brand. (Total utility industry capital spending, forecast to be about \$26.6 billion this year, peaked at \$40.2 billion in 1982. At a little over \$12 billion, spending for generating equipment is expected to account for less than half the total this year, compared with its peak of \$29.9 billion, nearly three-quarters of the total, in 1983.)

While some have questioned the wisdom of American utilities becoming dependent on foreign suppliers, Brand discounted those concerns. "Global sourcing is already part of our business environment. . . . It's too late to turn back the clock. We've already crossed the great divide."

The availability of spare parts is often mentioned as a potential Achilles' heel of foreign sourcing. But Brand said that Pacific Gas and Electric makes sure it has backup European suppliers for Japanese-made circuit breakers and seeks multiple sources whenever necessary. The sprawling California utility considered stockpiling critical spare

parts for certain items, he said, but has found "no justification for creating stockpiles that don't already exist for other reasons." Instead, procurement policies specify American standard parts even on foreign-supplied equipment or include spares in the initial purchase.

Key to the American strategy of foreign suppliers, according to Brand, has been a "solid understanding of our existing technology" and the results of decades of American utility and supplier-funded research—as well as work of their own in "marvelous R&D programs designed to spin off commercial products." A similar strategy could work for domestic suppliers, he added.

"For organizations like EPRI to lay groundwork for the breakthroughs we need, they should concentrate on R&D programs in this country," Brand urged. "For our participation in joint U.S.-foreign research to make sense, we should focus funds that we send abroad on programs with little or no domestic counterparts. We must recognize that our R&D funding dollars are important in maintaining American suppliers' remaining strengths."

U.S. equipment manufacturers remain world leaders in large steam power plant technology, in replacement components and services, and in new and innovative generation and T&D

IMPORT TRENDS IN KEY POWER PLANT EQUIPMENT

Percentage of New Supply Imported

Type	1972	1982	1983	1984	1985
Pumps and related equipment	2.5	5.9	5.9	6.2	6.2
Air and gas compressors	6.8	7.8	7.5	9.2	10.2
Valves and pipe fittings	3.3	8.8	6.9	8.3	NA
Blowers and fans	5.0	19.8	21.6	27.9	30.6
Turbines and generators	7.6	5.7	4.6	NA	NA
Power boilers	2.2	2.0	4.0	4.3	NA

Source: Black & Veatch, Engineers-Architects

technologies such as gas turbines and "smart" power control systems, said Brand. But the struggle for survival in the international marketplace is just beginning, he predicted. Likewise, utility efforts to adapt to the new business climate will intensify in the years ahead. So far, "our introduction to the world supply network has been beneficial to the utility industry. And it is helping us to keep our costs down. So we're not going to pull back into a protective, 'buy American' posture. . . . We want to work with the best equipment suppliers in the world. At the same time, we expect that many of those suppliers will be American."

Leveling the playing field

One of those American suppliers that intends to stay around, despite the sometimes draconian retrenchment it has undergone in recent years, is General Electric. Clyde Keaton, vice president and general manager for GE's industry sales and services, told the Advisory Council that GE's plan "is to continue as a leading strategic supplier to the electric utility industry around the world."

Keaton repeated the oft-heard complaint of American equipment suppliers, however, that while they must scramble to stay alive in an increasingly competitive U.S. market, the protected home turfs of their foreign rivals make for an unfair and uneven playing field. "We have strong feelings about the invasion of the United States by foreign suppliers. Don't get the wrong idea—we are for a free and open market."

About 20% of GE's industrial and power systems group sales of \$5 billion in 1987 came from offshore, he said.

But not from western Europe. There government-protected national markets have effectively excluded U.S. steam turbine manufacturers for decades. Keaton said that of 266,000 MW of generating capacity added in western Europe in the last 25 years, GE has been

unable to book an order for a single project. By comparison, foreign manufacturers have supplied about 10% of the new turbine capacity installed in the United States over the same period, he added.

"We want to compete in open markets, but when markets are closed to U.S. manufacturers, we believe the U.S. utility industry should not do business with those companies until their countries' markets are open to us," said Keaton. "In particular, we do not believe EPRI should sponsor research with companies whose countries are closed to U.S. manufacturing."

The problem of access to Europe's utility markets by American equipment makers is only part of a much broader and deeper U.S. trade deficit with all parts of the world. It grew from \$35 billion in 1981 to \$171 billion in 1987; the trade gap with members of the European Community (EC) alone has increased by \$36 billion over the same period.

An official of the Reagan administration's Office of the U.S. Trade Representative said the government has been increasingly vigorous in its pursuit of open markets abroad. J. David Morrissy, director of capital manufactures and materials trade policy, conceded concern, however, that as the EC proceeds to remove all barriers to trade among member countries by 1992 in key industries, including heavy electrical equipment, "the very same brick may be used to build walls to keep out non-EC producers."

The United States is making its concern clear to the EC and the individual countries, but "it may well be that these member countries will resist the EC initiative to open their markets as firmly as they have resisted the U.S. pursuit," said Morrissy. He noted that Congress has already played its hand in the case of high-voltage transformers, imposing a 30% "buy American" price preference on federally procured

units imported from countries whose markets are closed. (Sweden and Switzerland requested exemptions; Sweden was granted one last summer.)

Meanwhile, the government has tried to limit foreign access to federally funded research that could affect industrial competitiveness, particularly recent R&D in superconductivity. Policies to encourage more cooperative private research ventures have included legal exemptions from some antitrust constraints. More-favorable trademark and patent protections are being sought in the Uruguay round of trade negotiations. The national laboratories have been issued a number of presidential directives to increase technology transfer to the private sector.

"There is increased sensitivity to the contribution that research can make to U.S. industrial competitiveness, particularly manufacturing competitiveness," said Morrissy. "This applies not only to the original breakthrough discoveries, but even more to the follow-up commercial applications. . . . If trade and technology flow only in directions that disadvantage U.S. producers, we will be unable to maintain our competitiveness, or our standard of living, or, ultimately, our sense of national security."

Challenges for R&D

The issues raised by the speakers to EPRI's Advisory Council are of concern to many people both inside and outside the Institute and the utility industry. These issues relate not just to technology, or the economic health of domestic industry and the nation, or the balance of international trade, but to all these matters and more—and in a web of interconnectedness that makes simple characterizations of the problems and challenges elusive.

Yet it seems that nearly everyone who follows the electricity field has personal thoughts about what is happening and what it means. Later interviews with past and present EPRI man-

agement and several members of the Advisory Council who attended the April discussion sought reaction and insight. What is surprising, perhaps, is the similarity of views of what utilities and EPRI should make of the changes.

To Judith Warrick, a New York investment analyst and consultant and a member of the Advisory Council, there

is little utilities or even EPRI can do about the diminishing role of U.S. equipment suppliers. "To the extent that each utility has to be the lowest-cost supplier, they're going to have to go more to foreign suppliers if that is where the technological edge is—and, clearly, we're seeing a lot more of that happen.

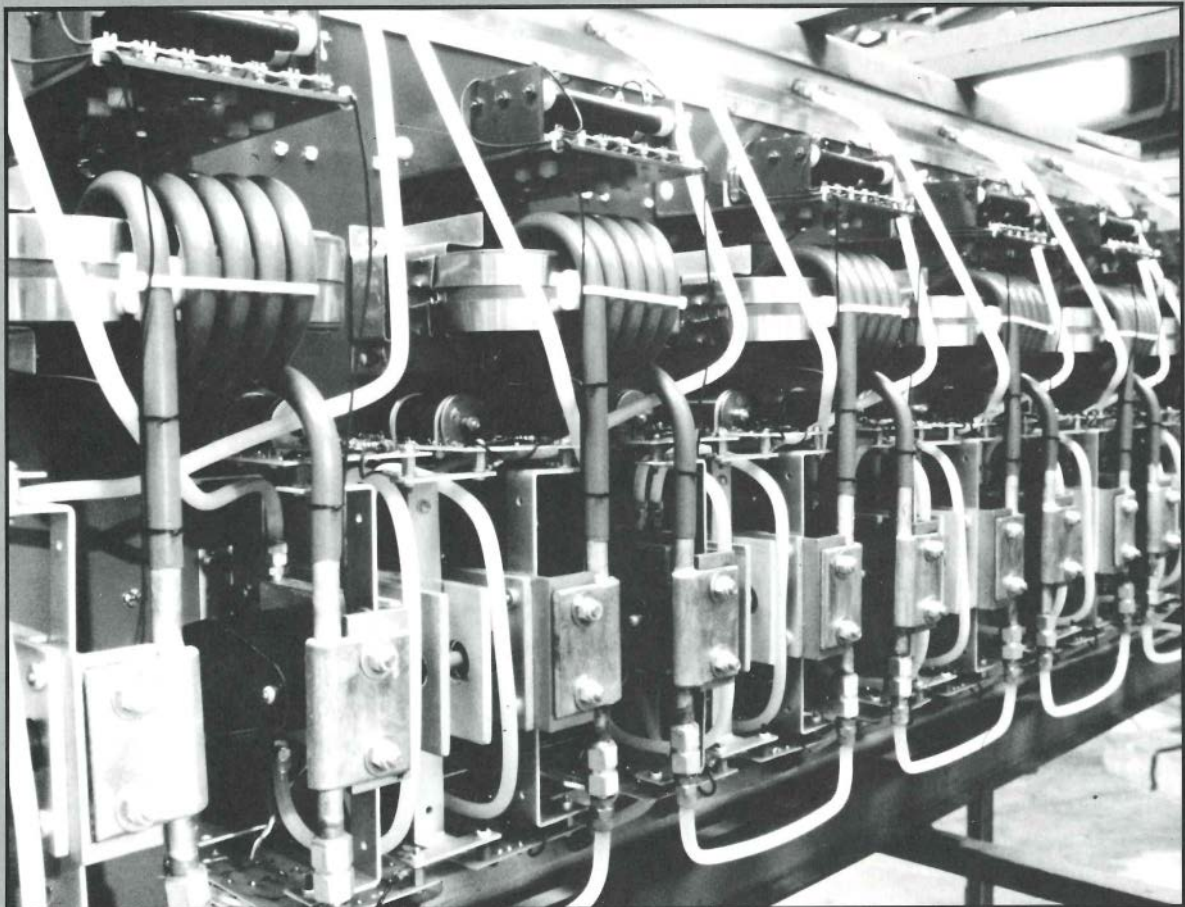
"The same is true for EPRI. . . . If the only people making some of the equipment that R&D money has to go into are foreign-based, and if we're faced with either having the product or technology from a foreign source or not having it, it seems to me EPRI has got to take the product," putting that ahead of concerns for supporting do-

UTILITY EQUIPMENT SUPPLIERS: THE CHANGING LINEUP

HVDC Equipment



For many years, Asea of Sweden, Brown Boveri of Switzerland, Siemens of West Germany, and General Electric all supplied high-voltage direct-current power equipment worldwide. But in 1987 GE sold its HVDC business to CGEE-Ahlstrom of France, leaving no domestic supplier; later that year, Asea and Brown Boveri merged.



mestic manufacturers, said Warrick. "I do think EPRI should take a leading role, however, in creating an awareness at the appropriate levels in the national government, at the state regulatory agencies, and through the member companies themselves that this is an industry which may well be hurt by the foreign trade issue and the barriers to competition worldwide that are clearly in place," she added.

The barriers to foreign markets are real and fly in the face of free-trade thinking about a global economy, agreed Herbert Woodson, an Advisory Council member and dean of engineering at the University of Texas. "I hate the term 'level playing field,'" said Woodson, "but I do agree with the manufacturers that we need to exert whatever pressure is available, including diplomatic pressure, to make sure we are able to compete in a global economy."

In any case, "results from EPRI-funded R&D, wherever it is done, should be available to American industry to manufacture and to utilities to use such that the industry gets its money's worth," said Woodson, noting the historical EPRI policy that requires R&D results to be available for license.

Worries about overdependence on foreign suppliers may be overblown, according to John Gibbons, director of Congress's Office of Technology Assessment and a recent Advisory Council appointee. "I haven't seen any evidence that we are dangerously over-dependent," he said. "Lacking that, it seems to be in utilities' interests to let the best suppliers win in open competition to provide the best products and services."

Whether the locale of manufacturing or R&D is domestic or offshore should be a consideration both for utilities and for EPRI, Gibbons added, "but it should be a subsidiary consideration." Decisions to go offshore for R&D "are bound to cause some frustrations, but

I would be loath for us to build a wall around our research enterprises just as I would be with respect to manufacturing enterprises."

Mergers and consolidations among heavy electrical equipment makers will continue, predicted Gordon Hurlbert, a Council member and former president of the power systems group at Westinghouse. But he noted an upside to the inevitable. "This trend is not necessarily bad. With higher volume for fewer vendors, they can afford higher levels of R&D spending and take more advantage of manufacturing economies of scale."

Hurlbert—who, after a 37-year career with Westinghouse, is now chairman of CSC Industries (a steel producer) and a member of the boards of Weirton Steel and Carolina Power & Light—believes that much of the concern over the ability of U.S. manufacturers to compete internationally will be negated by the very recent depreciation of the dollar against the yen and the deutschmark. The dollar's relatively high value through the early 1980s helped make U.S. goods more expensive to foreigners and foreign goods cheaper in U.S. markets. "This is a great self-correcting mechanism at work that will ameliorate the problem of U.S. vendors not being competitive," said Hurlbert. "It takes time for changes in currency values to work back through economies, but I think it's inevitable we will see some production shifting back to the States."

As for the implications of the Westinghouse-Asea Brown Boveri pacts, Hurlbert believes it's "highly probable that Asea Brown Boveri will own [Westinghouse's] transmission and distribution business" by 1992, "but as long as we have other domestic competitors, I'm not unduly concerned.

"As far as society is concerned, we can't look at just one industry. We have to look at the entire economic picture

and what it means in terms of jobs and investment," Hurlbert added. "I'm a free-trader, and I believe that what we lose on the apples we'll make up on the oranges and bananas. With more competition and investment we will be a stronger country overall, even with some disappointments for industry."

How should EPRI respond to the changing horizons in R&D? Hurlbert feels it should contract with foreign firms only if there is a substantial advantage in going overseas. He supports the policy that requires any product or invention from EPRI-funded research to be available for license. "And when EPRI does go outside the country for R&D, it's important to let the U.S. manufacturers and utilities know why."

Ultimately, said Hurlbert, where EPRI spends its over a quarter of a billion dollars a year in member-funded R&D is less important than that the best technology for improving productivity and competitiveness be made available and put to use by American utilities. "EPRI is uniquely qualified to absorb all the technology being developed around the world, to trade our technology for others' technology, but only on a quid pro quo basis. It is in the best interest of the United States and of American utilities to have a strong EPRI to get that technology, to get the maximum benefits from our R&D investments."

New roles for EPRI?

Getting the most for utilities' R&D dollars while working with a changing field of traditional equipment suppliers, innovative spinoffs or startups, and emerging new forms of enterprise for applying technology is a subject of considerable reflection among EPRI management lately. Separate conversations with past and present senior executives and a former long-time Westinghouse research manager brought ready agreement that changes are in store for EPRI, in terms of the companies it contracts with for R&D and its role as, in Presi-

General Electric: A Case Study in Change

General Electric's continuing commitment to the utility industry has been forged of a painful restructuring. As he detailed the changes to EPRI's Advisory Council, Clyde Keaton, vice president for industry sales and services, provided something of a case history on how a giant U.S. manufacturer has responded to international competitive pressures.

Keaton acknowledged "radical change" at GE since 1981, when Chairman Jack Welch began to take the \$40-billion-a-year company out of over 200 businesses—including housewares, consumer electronics, and, most recently, semiconductors—in which it could not be first or second in market share. The changes have involved cutting the work force by over 100,000, but also investing nearly \$17 billion in productivity improvement and new products as well as numerous acquisitions (e.g., RCA) and joint ventures. GE is discussing a possible alliance in the power systems business with a number of manufacturers in Europe and the Far East to counter the Westinghouse-Asea Brown Boveri joint ventures.

Several factors transformed GE's industrial and power systems business from the largest and most profitable GE enterprise in 1984 to one forced into major restructuring: the completion or cancellation of backlog orders in manufacturing plants, major power plant cancellations (some fossil but mostly nuclear), the completion of remaining nuclear projects, and a depressed short-term outlook for future turbine and transformer sales.

In 1976 GE shipped turbines totaling 20,000 MW of capacity; by 1986 shipments amounted to less than 2000 MW. The company closed five of nine turbine factories, slashing production capacity by half, but it also invested over \$100 million in the consolidation and in developing its new advanced 7F gas turbine. Much emphasis has shifted to servicing the 12,000 GE steam and gas turbines operating around the world. New offshore orders, meanwhile, have picked up and are now almost one-third of domestic sales. After some tough years in the turbine business, Keaton said, "we've weathered the worst of the storm and today feel very good about where we are."

The case of large transformers was different. By 1986 sales volume had dropped almost 90% over a decade of unprofitability. Technology development was stagnant and the product, although a challenge to manufacture, had become a stock commodity. GE "didn't see any hope of turning the

situation around," said Keaton, and so decided to quit the high-voltage transformer business. On the other hand, the kilowatt-hour meter business continues to offer opportunities for differentiating the product (for example, with new electronic models), and GE has revitalized distribution transformers with its market-leading low-loss amorphous metal technology, developed with EPRI support.

Prospects in the nuclear field remain pretty bleak. "We've had to face the fact that the domestic nuclear market for new plants has disappeared altogether, with no hope of a return in the foreseeable future," said Keaton. So GE is focusing on servicing and fueling the existing fleet of boiling water reactors and has remained an active player by leading the development of an advanced BWR planned by Tokyo Electric Power. The advanced BWR is expected to eventually become the standard offering if the domestic market returns.

To further reduce costs and maintain a competitive position, GE fused its four sales and service divisions in industrial and power systems together. "We're making a transition from being a supplier of equipment and services to being a supplier of solutions, a distinction we believe is critical as the industry looks for fewer, but more strategic, suppliers." The company has even entered into power plant maintenance contracts with utilities in which it shares the risks and rewards for improving availability. In short, said Keaton, "GE is far from a diminishing U.S. supplier." □



dent Richard Balzhiser's words, "a broker of technology."

Referring to the recent changes in the power equipment field, Milt Klein, vice president for industry relations and information services, noted: "In a broad sense, the movement of these kinds of manufacturing activities overseas could have profound implications. The United

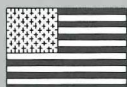
States has been preeminent in advancing technology. Our economic strength has been tied to that capability. Can that strength be maintained if manufacturing and its management shift to other countries, or will the center of gravity of technical advancements also shift?"

Frank Young, associate director of the

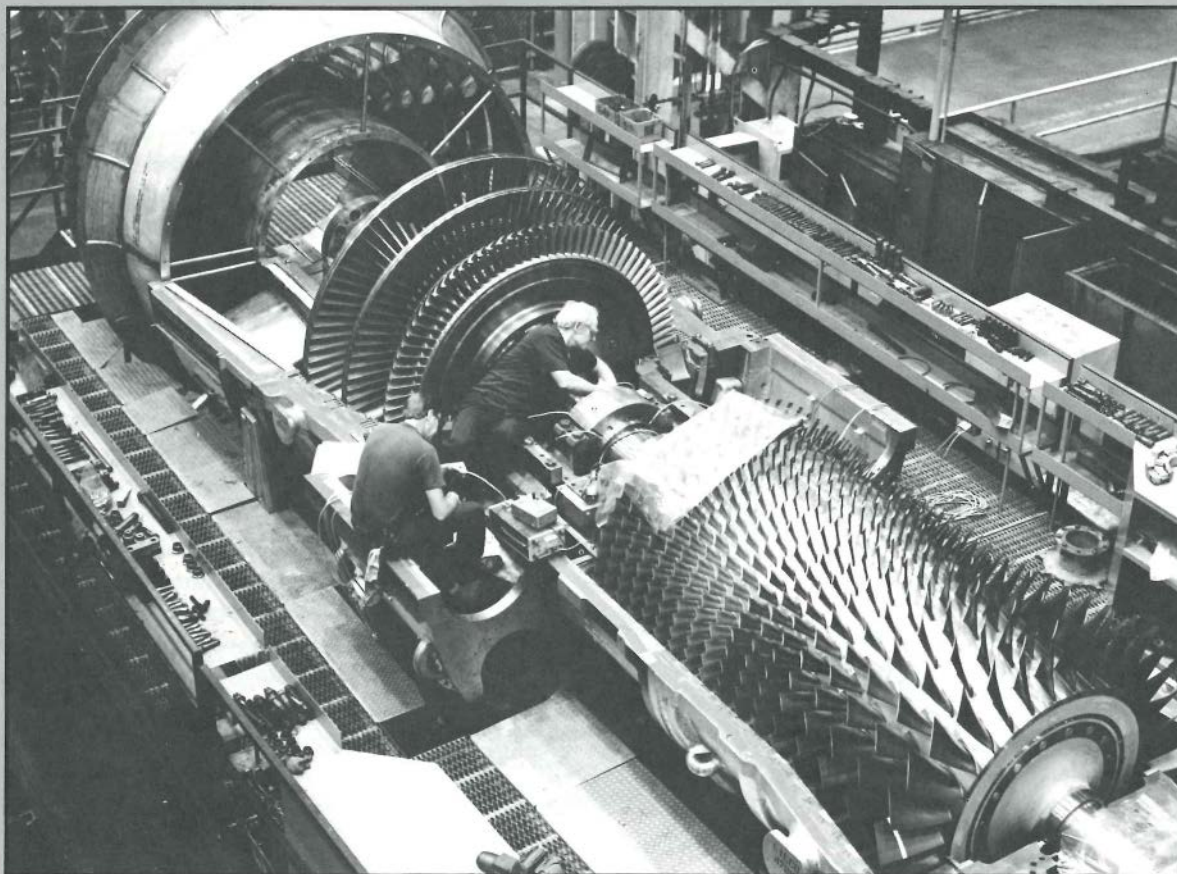
Electrical Systems Division and former head of high-voltage transmission research at Westinghouse, agrees that the present trends could shift vital engineering talent out of the United States. "Over time, say, in 10 years, will all the engineering be done in Basel, Switzerland, or in Ludwiga, Sweden, or in Muncie, Indiana?" Young wondered.

UTILITY EQUIPMENT SUPPLIERS: THE CHANGING LINEUP

Gas Turbines



The only remaining domestic manufacturer of large utility combustion turbines is General Electric. Westinghouse's production of turbines 50 MW and smaller has moved to Canada, while Mitsubishi manufactures larger models under joint agreement in Japan for sale by both companies. Asea Brown Boveri and Siemens' Kraftwerk Union subsidiary both produce turbines in European factories for sale in the United States.



"Where does the intellectual initiative, the intellectual property, go?"

Young said EPRI is already talking with and looking for smaller technology firms to fill the gaps in development capabilities in some areas of business excited by traditional suppliers. "There is hope that out of the ashes of the demise of the domestic manufacturers will rise some entrepreneurial firms that will be the new innovators. My hope is that we will take it on as an intellectual challenge and find innovative ways of dealing with it, to think big and charge ahead."

As for the more practical, potentially political issue of where or with whom R&D funds are spent, Chauncey Starr, the Institute's vice chairman and founding president, recalled that "EPRI, as well as our Board of Directors, has always taken the philosophy that R&D should be done wherever the greatest competence of people exists." In EPRI's experience that has, with few exceptions, been U.S. companies. "Everything else being equal, sure, we would work with an American company, but if the maximum R&D skill is in a foreign company, we'll go where the major competence is. The results of the work, of course, must be available to the industry, by licensing through a U.S. manufacturer or some other way."

The matter has become an issue several times in EPRI's history, said Starr. Most cases were resolved quietly, as is EPRI's preference in business dealings. One case, in 1983, created a stir in certain business and political circles—namely, EPRI's choice of Switzerland's Sulzer Brothers for critical R&D to advance power plant pump technology. At the time, Starr had already turned over the helm at EPRI to Floyd Culler, but he remembers the "painfully fought battle." Looking back, Starr believes things worked out for the best: regulators were satisfied that EPRI's decision was rationally considered, and American pump manufacturers ultimately

enhanced their own technology and competitiveness.

For his part, Culler sees challenges and an expanding role ahead for EPRI as utilities rely less on their traditional suppliers for knowledge and expertise in applying technology. He thinks utilities will be looking more to EPRI for design and engineering assistance, personnel training in new technology, and assistance in collecting and analyzing ever more specific data on plants and systems for feedback to utility engineering staffs. "Utilities are becoming more dependent on EPRI for our savvy and knowledge of what is possible and as a catalyst for technology transfer," said Culler.

He acknowledged that "with suppliers like GE and Westinghouse cutting out most of their innovative R&D, EPRI will find it more difficult to place meaningful R&D contracts within the U.S." But as new relationships evolve among international suppliers, the pendulum will swing. "The U.S. is still the largest market in the world, and the alliances between our big manufacturers and big overseas suppliers could move the center of gravity for manufacturing to the U.S. It's not inconceivable."

Even if that happens, EPRI's relationships with industry suppliers are changing. "The organizations that historically have been our largest contractors are showing less interest in power systems R&D," said President and CEO Balzhiser. "They're generally less willing to pursue mid- to longer-term work and are increasingly reluctant to cost-share significantly.

"The traditional suppliers today look at the utility business in a much shorter term context. They prefer to deal with less risk and to use their R&D resources more strategically. EPRI provides a means through which the utility industry can help shape its technological future and share the risk with capable and committed equipment suppliers in the future. Together, I believe we can

continue to push back the technological frontiers," said Balzhiser. "We're looking more widely for organizations with an interest in advancing power technology, and we are devoting more time and attention to ensuring that our products get licensed and used in the field," he added.

As EPRI's chief executive sees it, the challenge also presents opportunities for EPRI and its constituency. "We may be in a position to begin to formulate, with the help of others that have venture capital experience, the basis for investments in some new business opportunities—ideas that arise out of new technology we develop or see in need of investment. EPRI members interested in diversifying may find attractive investment opportunities in startup firms with products for use by utilities or their customers."

Shrinking world, quickening pace

Broadening the nature of EPRI's R&D business arrangements is the kind of change that Balzhiser thinks will ultimately make EPRI "more organizationally resilient." But technology is what really excites him. As Balzhiser muses on the future, it is technology that drives his vision of change.

"There will always be people and companies, whether in Zurich, Stuttgart, or Atlanta, with an interest in supplying the utility equipment markets. But I think there will be a lot more volatility in the field as markets rise and fall and as the technology changes more quickly," Balzhiser said. "The pace at which technology will obsolete its forerunners is going to quicken. That has many implications for R&D and for investment. I don't think any of us are smart enough to know what all of them are." ■

This article was written by Taylor Moore.



Putting the Freeze on Refrigeration Costs

Supermarket refrigeration accounts for an important fraction of energy use in the commercial sector. A year of on-site testing and analysis has shown that energy-efficient equipment can cut refrigeration bills by more than 25%.



The modern supermarket depends on electricity for lighting, for heating, and—above all—for refrigeration to protect a vast selection of meats, dairy products, fruits, and vegetables. In the United States today, the 35,000 supermarkets in operation account for approximately 4% of all electric energy used, with about half of this supermarket energy use attributable to refrigeration equipment.

As competition has narrowed profit margins, energy efficiency has become an increasingly important issue for supermarket owners. According to the Food Marketing Institute, the energy bill for an average supermarket is approximately equal to the pretax profit. For supermarket owners, who typically must sell \$100 worth of groceries to earn \$1 in profit, reductions in energy costs can have a direct and dramatic effect on a store's bottom line. One result of these low margins is increased attention in the industry to new, more energy-efficient refrigeration technology, including improved compressor and condenser designs, electronic control systems that match compressor capacity to refrigeration loads, and innovative subcooling and heat recovery strategies.

While lowering energy bills for supermarket owners, the new technology also provides opportunities for electric utilities. Supermarkets constitute an important group of utility customers with large, round-the-clock electricity requirements. Also, supermarkets use the most energy on hot summer afternoons, a demand pattern that closely coincides with the peak demand on utility generating facilities. This gives utilities a chance to improve their load factors through the promotion of equipment that uses less energy at peak periods. In addition, the equipment can help utilities head off competition from both gas-fired refrigeration and cogeneration systems that are now becoming available for supermarkets.

Recognizing the potential benefits of the new refrigeration equipment to both utilities and their customers, EPRI launched a unique field demonstration and model development project in 1986 at a Safeway supermarket located near the Institute in Menlo Park, California. Pacific Gas and Electric is cosponsoring the project, and two other key participants are providing cost sharing and technical assistance: Safeway Stores, one of the largest U.S. supermarket chains, and Hussmann Corp., the leading supplier of commercial refrigeration equipment in the country.

For the project, a state-of-the-art refrigeration system was installed alongside a conventional system in the store's machine room. This arrangement allows researchers to alternately operate the two systems for comparisons of electricity use and demand. They aim to document the energy savings achievable through use of the new equipment, and to collect data for the development and validation of software tools that will help supermarket owners select the best available equipment for their location.

"This work represents the first objective evaluation of the state of the art in supermarket refrigeration," says Roland Ares, Hussmann's vice president for commercial refrigeration equipment. "Results show that supermarkets can achieve impressive cost and energy savings through today's best practice."

Documenting just how impressive these savings are is the job of Foster-Miller, Inc., a contractor working with EPRI to analyze the test data. Results from the project's first phase, representing over a year of continuous operation of the test equipment, showed energy savings of more than 23%. And researchers have shown that even greater gains are in the offing for much of the United States. Foster-Miller's David Walker explains: "The weather in Menlo Park was particularly mild during the test period, which moderates some of the system's

efficiencies. In more characteristic weather—and in more extreme climates—we would expect higher energy savings for the new equipment.”

Designing the demonstration

Plans for the demonstration originated at an EPRI-sponsored workshop in 1984, where experts from the supermarket, utility, and refrigeration equipment supply industries met to identify research opportunities to improve the technology and encourage its use. The consensus of opinion among the participants was that doubts about the effectiveness and reliability of promising new equipment were posing a barrier to its acceptance in the supermarket industry, a generally conservative business where spoilage is a paramount concern.

“Before trusting their inventory to new equipment, people in our industry need to know that it’s going to work,” says Richard Oas, engineering manager for Safeway. “And even when there is confidence in the technology, it’s difficult for the store owner to quantify the energy cost savings that new equipment can provide, because of the great degree of variation in the operation and maintenance of refrigeration equipment in our industry. We needed an objective look at the new equipment to help put different store experiences and vendor claims into perspective.”

Responding to these needs, EPRI laid the groundwork for the field demonstration in a research plan developed by Science Applications International in 1985. The plan incorporated evaluations of several key technologies that were found to be ready for demonstration. After reviewing these findings, EPRI research managers selected a state-of-the-art system for the demonstration that would put several different components and subsystems to the test in various combinations.

Finding a suitable test store was also important to the project’s success, and the Menlo Park location fit the bill in

many respects. Open 24 hours a day and featuring a representative variety of refrigerated display cases and walk-in boxes, the store provided a model of year-round, round-the-clock energy use at a supermarket using conventional refrigeration equipment.

The store’s conventional equipment includes 23 stand-alone compressors, an electric defrost system, and electromechanical energy management controls. “These components—generally representative of systems in common use around the country—gave us a baseline against which to compare the state-of-the-art equipment,” says Morton Blatt, who manages EPRI’s research on commercial building systems. “We were confident that there were significant savings available from a few key technologies. This project allowed us to establish a ‘field laboratory’ for evaluating the performance of these energy-efficient components and subsystems on site.”

The physical layout of the Safeway test store was also ideal. It had a large machine room, with ample space for installation of the second refrigeration system, which includes racks of compressors, condensers, heat exchange equipment for subcooling, and a data monitoring and communications station. Furthermore, pipes linking the refrigeration equipment to the store’s display cases were easily accessible from an underground garage. This allowed researchers to install the additional piping and instrumentation without disrupting the normal operation of the store.

State-of-the-art strategies

The heart of the energy-efficient refrigeration system installed at the test store is the multiplex compressor system, which accounted for 43% of the overall energy savings during the first phase of the project. The system’s 13 compressors, arranged on three racks, vary in horsepower; each rack shares a common refrigerant intake and discharge. Programmable electronic controls cycle the differ-

ent compressors on each rack in the combinations that best match capacity to the changing refrigeration loads of different store displays.

This multiplex compressor system contrasts with the store’s conventional system, each of whose 23 compressors is dedicated to an individual load or group of loads (display cases, walk-in boxes, or meat preparation rooms). Since these stand-alone compressors are not designed to be repeatedly cycled on and off for short periods of time, they can waste energy by running at greater capacity than is needed at a given juncture. Overall, the multiplex system uses fewer compressors and less horsepower to more efficiently meet the same refrigeration load.

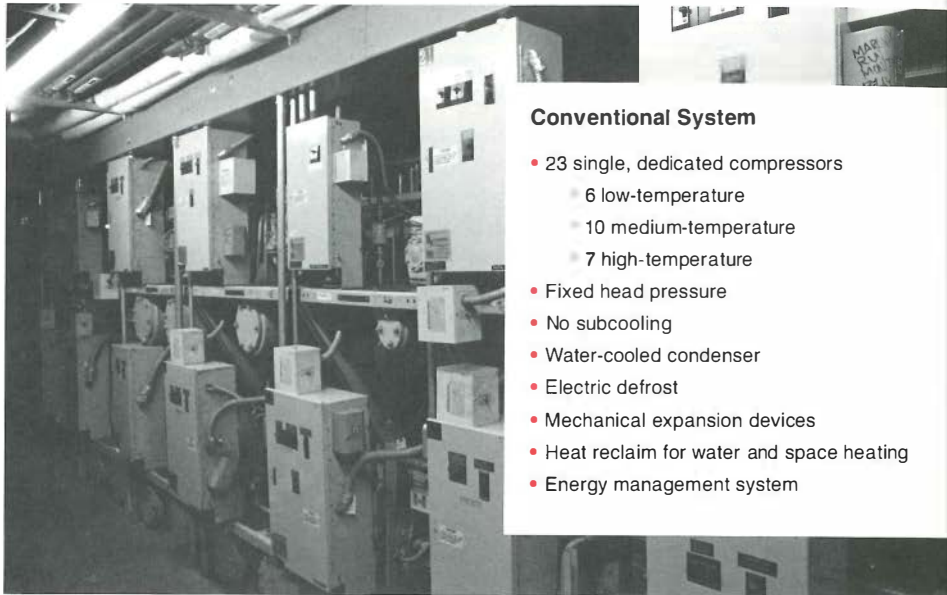
Another energy-saving feature of the new system is a control strategy that allows the compressors’ refrigerant discharge pressure, or head pressure, to be adjusted to the ambient temperature outside the supermarket. This floating-head-pressure strategy is implemented by controlling the fans on another state-of-the-art component, an evaporatively cooled condenser, in response to changes in outdoor temperatures. On cold days, when the condenser is rejecting heat to a lower ambient temperature, the compressor discharge pressure and temperature can be reduced, and the entire system gains in efficiency.

Moreover, even on warm days, the evaporatively cooled condenser uses less energy than the water-cooled condenser employed in the store’s conventional refrigeration system. Use of the evaporative condenser accounted for 22% of the energy savings during the first phase of the project; the floating-head-pressure strategy accounted for about another 16%.

The system achieves added energy efficiency by supplying additional cooling, or subcooling, to the liquid refrigerant leaving the condenser. Because the subcooled liquid can pick up more heat in the display cases, less compressor power is needed to meet the same refrigeration load.

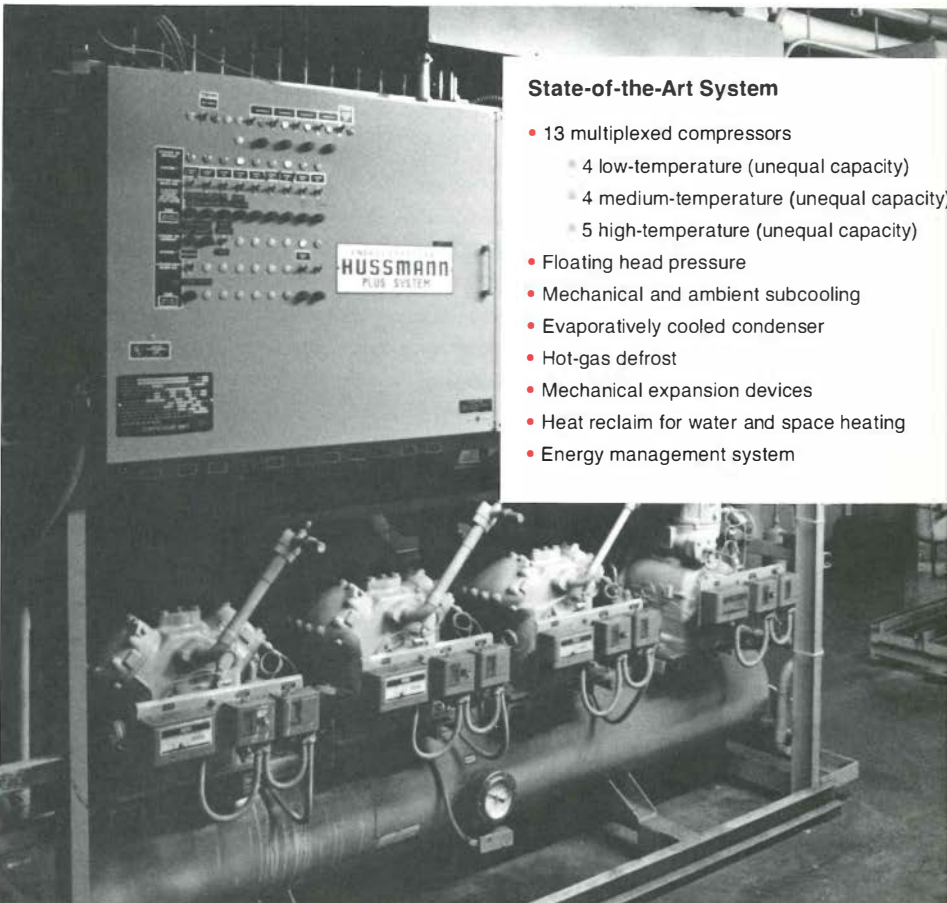
Comparing Old and New

To compare performance under identical conditions, researchers installed and operated a state-of-the-art refrigeration system in alternation with a conventional system already in place at a Safeway supermarket in Menlo Park, California. Compressor design was one of the most basic differences tested in the one-year demonstration. In the conventional system, each compressor is dedicated to a specific load; with the new system, compressors with uneven capacities are multiplexed so that they can be cycled on and off in combinations that more closely match the cooling loads they serve. The multiplexed system allows the use of fewer compressors and gives higher overall efficiency.



Conventional System

- 23 single, dedicated compressors
 - 6 low-temperature
 - 10 medium-temperature
 - 7 high-temperature
- Fixed head pressure
- No subcooling
- Water-cooled condenser
- Electric defrost
- Mechanical expansion devices
- Heat reclaim for water and space heating
- Energy management system



State-of-the-Art System

- 13 multiplexed compressors
 - 4 low-temperature (unequal capacity)
 - 4 medium-temperature (unequal capacity)
 - 5 high-temperature (unequal capacity)
- Floating head pressure
- Mechanical and ambient subcooling
- Evaporatively cooled condenser
- Hot-gas defrost
- Mechanical expansion devices
- Heat reclaim for water and space heating
- Energy management system

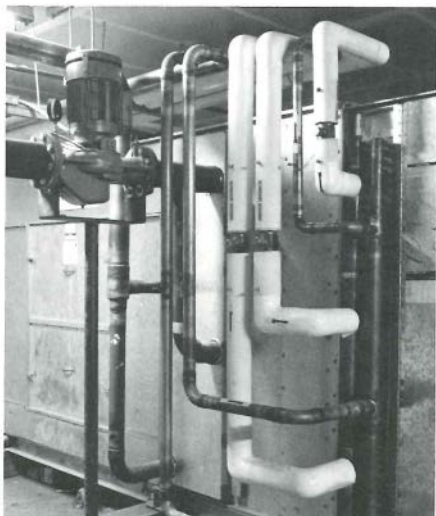


Data acquisition room

Defrost timers

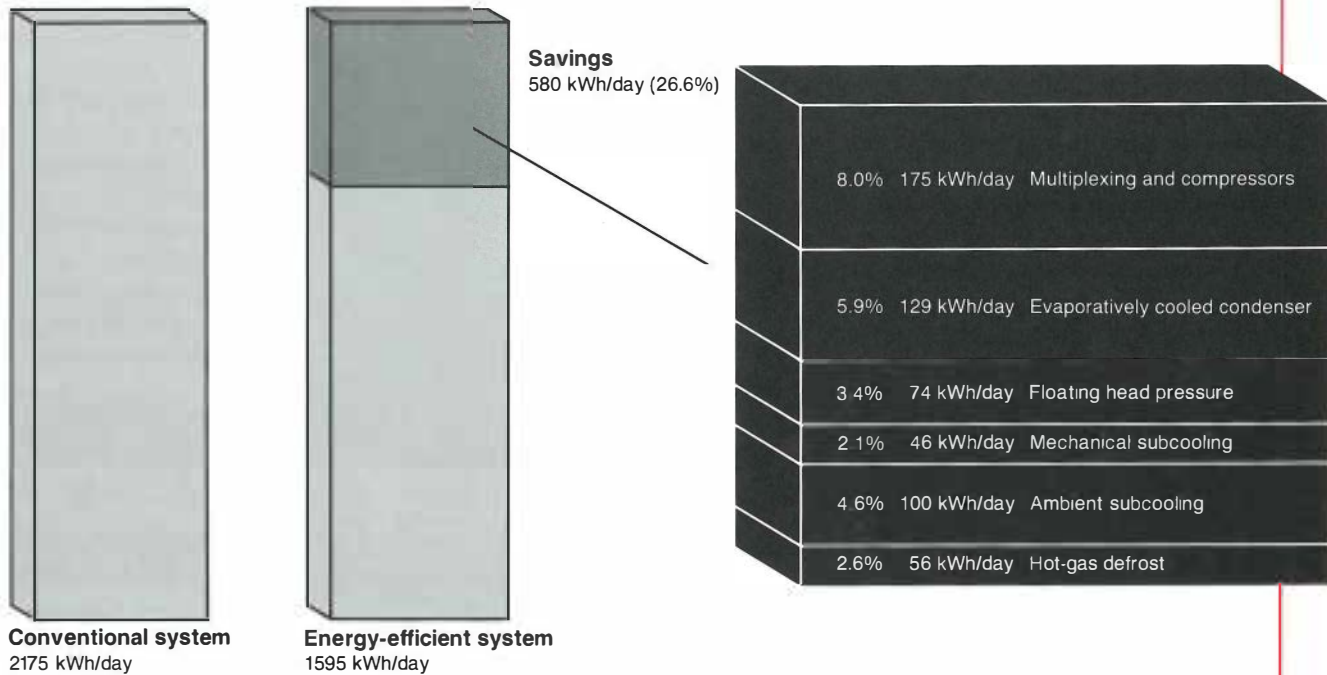


Air handler



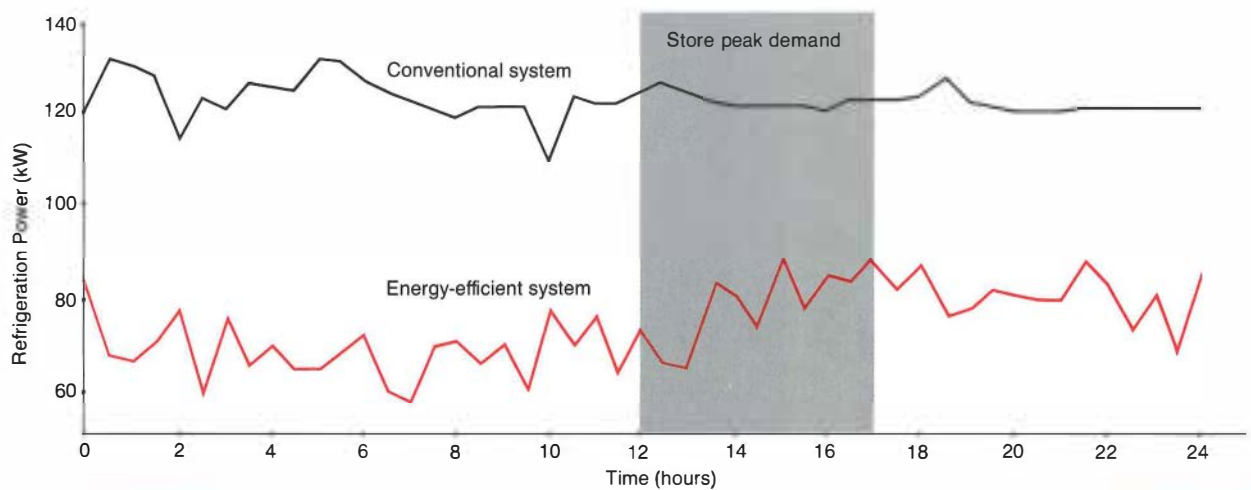
Saving Energy

Software developed to generalize data from the Safeway experiments shows that optimized operation of the store's state-of-the-art equipment during a year of typical weather would reduce electricity consumption for refrigeration by nearly 27%.



Lowering Demand

Baseline demand calculated by the software model demonstrates that the multiplex refrigeration system draws considerably less power on a hot summer day than the conventional equipment. During the period from noon to 5:00 P.M., when the store's peak demand typically occurs, refrigeration demand savings for the multiplex system amount to between 28% and 40%.



Both ambient and mechanical subcooling strategies were demonstrated at the test store, together contributing a little more than 6% of the total energy savings. Ambient subcooling, which is most effective during cool weather, involves the addition of a heat exchanger just downstream of the condenser. Mechanical subcooling, more practical in a warmer climate, uses both a heat exchanger and a small compressor. Special receiving tanks on the compressors keep subcooled liquid from mixing with refrigerant that has not been subcooled.

While subcooling strategies make the system more efficient at absorbing heat, a hot-gas defrost feature improves energy efficiency by putting waste heat to good use. This feature channels hot gas from the compressor discharge or warm gas from the condenser to display cases for defrosting, which is required several times a day. Conventional defrost schemes are based on electric resistance heat; hot-gas defrosting proved to be more energy-efficient, accounting for 13% of the total energy savings. In addition, the state-of-the-art system used heat reclaim controls to make compressor waste heat available for space and water heating in the store, a common practice in the supermarket industry.

Science behind the scenes

Researchers tested the state-of-the-art system in many different configurations. The tests alternated between baseline (full capability) operation of the new and conventional systems and routines in which individual components and subsystems were disabled. This flip-flop operating strategy, constantly switching from one system to the other, allowed researchers to compare the performance of the different systems in responding to the same outdoor weather conditions and air temperatures inside the store.

Throughout the test the heavily instrumented refrigeration systems were closely monitored for electric energy use, as well as for other parameters (such as

compressor head pressures) that will help researchers analyze energy use. Data were collected and stored in a computer on site and transmitted to Foster-Miller for analysis.

Test results show an overall electric energy saving of 23.2% with the new system, along with an even greater typical reduction in coincident utility peak demand—about 30%. In comparison with the conventional baseline system, the state-of-the-art equipment saved the equivalent of 580 kWh per day, or about 200,000 kWh per year. For a large supermarket this would mean that the cost premium (about \$20,000) of choosing the high-efficiency system would be recovered in less than two years at typical utility rates.

As good as the economics have proved to be, EPRI research managers emphasize that these results reflect operation in uncharacteristic weather and are probably closer to the lower bound of what supermarkets can expect. The unusually mild winter in northern California during the test period limited the efficiency gains available through floating head pressure and ambient subcooling—strategies that improve system efficiency most dramatically during periods of cold weather. Similarly, a cool summer limited the savings from evaporative condensing and mechanical subcooling—strategies that offer the greatest efficiency benefits during hot weather.

In addition, the condenser's minimum-pressure controls were set at a higher-than-optimal level in order to ensure proper operation of the expansion valves. This caused subcooling to occur in the condenser, eliminating any advantage anticipated from operating the ambient subcooling unit. (The condenser flooding also compromises some of the floating head pressure saving that could otherwise be achieved.) As a result, ambient subcooling was the only subsystem that did not add to the system's overall efficiency gains under the test conditions.

Foster-Miller has now developed a PC-based software model that can generalize the Menlo Park results for a variety of weather and climate conditions. By running the prototype model with a local weather tape from the National Oceanic and Atmospheric Administration, researchers calculated that the Safeway energy savings would have been 27% and demand savings would have been as high as 37% during the peak period (12 noon to 6 p.m.) for a typical meteorological year. Designed for use by utilities or supermarket engineers, the software model should be a particularly valuable tool, producing both energy use and demand profiles for energy-efficient refrigeration equipment at particular sites. The analysis software will be offered to utilities for field testing when development is completed in 1989.

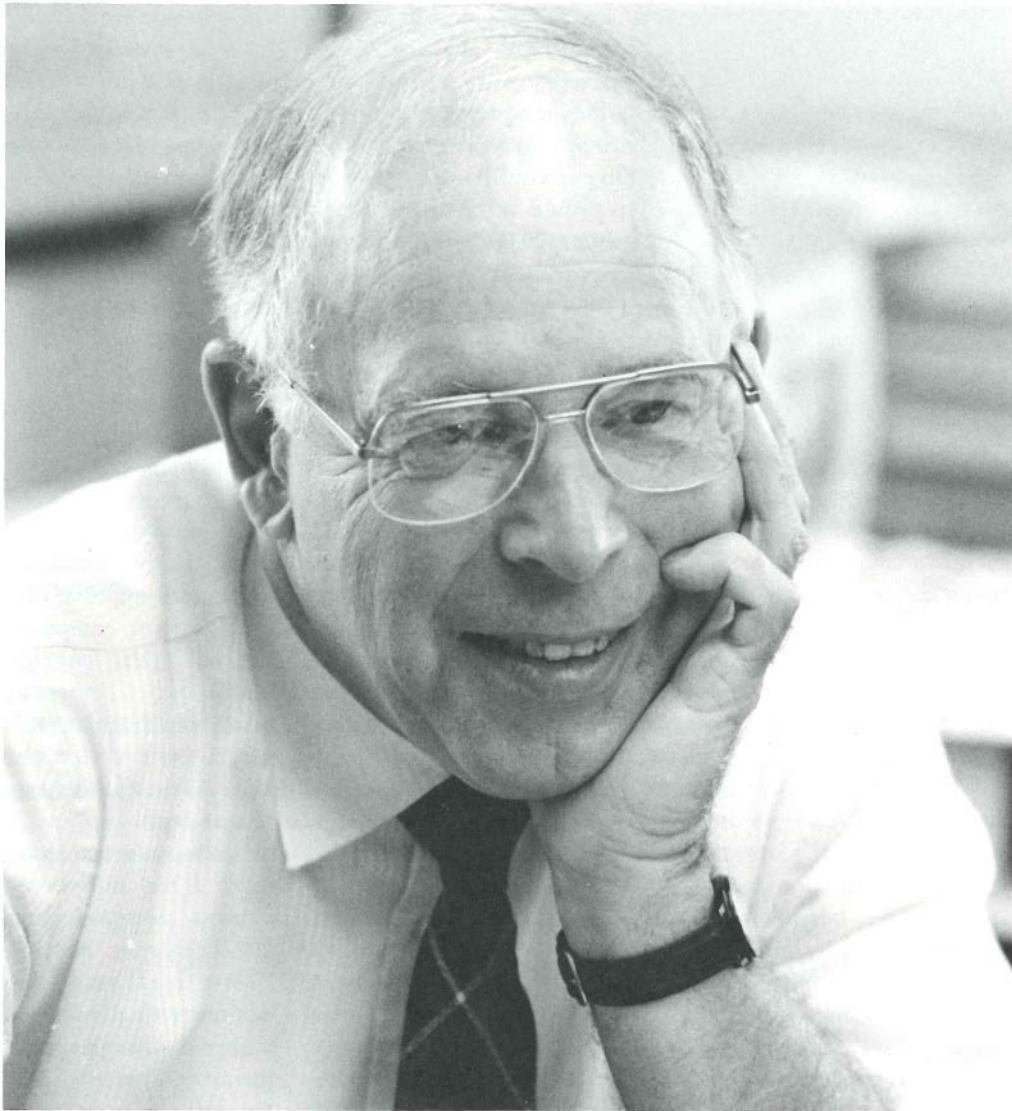
In the meantime, researchers at the Safeway test store are conducting a second phase of experiments. "This work will concentrate on retrofit equipment—add-ons or replacement components to help stores improve the performance of their present equipment," says David Walker. "We're looking at a number of possibilities . . . innovative compressors, liquid-suction heat exchangers for display cases, new electronic control strategies—basically anything that might help save energy."

Is the Safeway experience likely to make a real difference in how supermarkets approach energy efficiency? EPRI's Morton Blatt believes it will. "We've made some important steps in demonstrating the savings that can be achieved through application of state-of-the-art equipment. The information and the software resulting from this work will give the supermarket industry the confidence it needs to pursue more efficient electricity use . . . and save money in the process." ■

This article was written by Jon Cohen, science writer. Technical background information was provided by Morton Blatt, Energy Management and Utilization Division (Customer Systems Division).

JOHN GIBBONS

Pursuing the Conservator Society



His Office of Technology Assessment advises Congress; he advises EPRI. In both instances, Gibbons and his client groups are learning how to use energy and other resources more thoughtfully and efficiently.

Even before meeting John Gibbons, you sense something of his management style. His front office in Washington, D.C., features the *OTA Joke Book*, a three-ring anthology of current cartoon humor about scientists and technologists—mostly about how the rest of us view them and their work. It comes across that science and technology are simultaneously precise and ambiguous forces in U.S. society.

Gibbons heads the Office of Technology Assessment, the smallest agency of Congress. OTA's reports, produced by a staff of under 200, often propel it directly between contradictory positions, contentious personalities, and highly charged arguments in Congress on the promise—or the threat—of a technology. As a consequence, the agency is highly visible, widely quoted, and surprisingly influential.

How this happens becomes clearer when Gibbons summarizes what OTA does. "We act on requests from congressional committees. First, we find out what's known about a subject and set aside everything that seems to have consensus. Second, we focus the arguments, get down to the core issues that need to be resolved, and explain why experts are coming to different conclusions. Finally, we spell out, as much as possible, the legislative options Congress can use to help solve the problem—despite the uncertainties that remain in many of their heads, and ours."

With its urgency and range of subject matter, the work is at times like a pressure cooker for Gibbons. It is more than sufficient training for one of his other roles, that of an EPRI Advisory Council member. The Council, composed of up to 25 individuals from both public- and private-sector occupations outside the electric utility industry, is a useful reality check for EPRI management. Council members offer consensus views and occasional expert opinions on the content, balance, and direction of the collective

R&D program planned and managed by the Institute.

How did Gibbons come to be invited to Council membership three years ago? "I've a feeling that my past involvement with issues of energy efficiency and environmental links to energy gave me some standing. Also, I'm from government but not associated with the administration. My almost unique bipartisan position in town makes me a ready candidate."

Gibbons is forthright and good-natured. There's a lot of conviction in what he has to say about the technology that comes under OTA scrutiny. His principles show through in short order, but so does an easy detachment and modesty. He's a channel for what OTA learns and delivers to Congress, but he doesn't claim to own the knowledge. Neither does he accuse or blame others who do seem to take a more proprietary attitude.

The path into science

The personality, the principles, and the past involvement with energy issues all evolved from a boyhood in the Virginia town of Harrisonburg. "I came in with the crash—1929," says Gibbons. "My father was the business manager and treasurer at Madison College. But my ancestors had been in the Shenandoah Valley since the eighteenth century, so I could drop in at about every fourth house on any street and find a relative.

"It was an economically depressed time, but it was a comfortable place and a wonderful way to grow up—in terms of understanding who you are and how much you're part of the greater whole." Gibbons admits that it all sounds a bit like a television series of several years ago. "Well, yes. In fact, the setting for *The Waltons* was just over the ridge, in Albemarle County."

Still pondering his youth, Gibbons remarks that it often takes time to put past events into context and appreciate their significance. He remembers an early and general fascination with science, "a sense of wonderment about how things

work." But the mention of Hiroshima in 1945 sets off a chain reaction of specific memories.

"I knew exactly what it was when the newspaper said *atomic bomb*. Years before, when I was around 10, there'd been an article in one of the weekly magazines—*Collier's*, I think—that talked about the discovery of fission and the opportunities in this new source of energy. I read it with enormous fascination, but after that the subject totally disappeared from the press."

Then came the summer of 1943, when a vacationer on a Virginia beach affirmed 14-year-old Jack Gibbons's interest in physics. "He must have been one of the guys from Oak Ridge," Gibbons says today. "He drew in the sand some nuclear reactions having to do with neutrons and heavy elements, and he explained how those things worked. It really intrigued me, and when I went off to graduate school at Duke six years later, it was to study nuclear structure."

What Gibbons calls his "tour" in physics continued for most of the 15 years following his 1954 doctorate. "It was fun, exciting to do basic research. Groping in the dark is the best way to describe it.

"I did a year of post-doc at Duke," Gibbons goes on, "using neutrons to explore how nuclei get excited, how they settle down, how they move—how they transmute. Then I went to Oak Ridge, to the national laboratory there, for two reasons. One was an excellent physics division with a good accelerator and some interesting people with a commitment in my area. Also, I liked that part of the country—mountains, and within a 10-hour drive of my part of Virginia." The ambience became even more attractive a year after his arrival. "I'd met Mary Ann at Duke, now we were married, and I felt that the Oak Ridge community was very conducive to raising a family."

Today, more than 30 years later, three daughters are grown and following their own career and family interests. Gibbons jokes that he's "sort of slave

labor"—helping Mary in a new small business, helping Diana restore a Victorian house, and working around the yard when visiting with Virginia. "It's very pleasant to have kids who still like you when they grow up," he says. "Ours like to get together. In a way, they never leave home—their needs just change, and we have a lot of fun."

Starting an environmental change

For 15 years at Oak Ridge National Laboratory (ORNL), Gibbons was a physicist and group leader in nuclear geophysics. His work dealt with the origin and evolution of the heavy elements in the solar system—"proving we're all made of star dust," he says. "I call it solar system geriatrics." But he stepped out of the physics division on several occasions for special tasks; one time it was to work on civil defense, another to organize a post-doctoral program for the Oak Ridge Associated Universities.

By 1969 Gibbons realized that he was itching for a complete change. Basic research had been rewarding, "but I had other interests, and there were other problems that called for attention. Energy generation, for example," he adds. "I remember wandering off to seminars on molten-salt reactors."

This was also a time when ORNL was becoming interested in the management of waste heat from power plants. The timing was right. Feeling that it was appropriate for the laboratory to move aggressively in matters of energy and the environment, Gibbons accepted an invi-

tation from Alvin Weinberg, ORNL's director, to initiate a study of the environmental effects of hot water discharges.

As things turned out, not only was Gibbons moving away from nuclear physics; he was also departing from supply-side energy technology. As environmental program director for the next four years, he organized ORNL research on energy demand and conservation, regional analysis of environmental systems, and the environmental impacts of resource use.

It wasn't all smooth sailing. Gibbons describes a National Science Foundation study called "Research Applied to National Needs" and his dilemma in proposing ORNL research on the environmental effects of energy systems. "Here we were, a nuclear lab in the middle of strip-mine country. Any way we might go on the impacts of nuclear or coal-based energy supply, we'd have a problem with somebody. Then it hit me—there was the whole demand side. What do we know about that?"

The potential for better efficiency in energy use quickly became apparent, with air conditioners standing as the first dramatic example: higher-capacity units with increased efficiency were already being built (at little added cost), not to conserve energy but to avoid overloading standard household circuits. Gibbons was off and running, and his reports from ORNL in the early 1970s were seen and noticed. The environmental effects and implications of energy systems were coming to center stage in the

United States at the time, giving an incentive to energy efficiency and conservation measures.

However, demand-side research increasingly called for the talents of economists, market researchers, and lawyers and for the use of social science and public policy analysis. Staff resources at Oak Ridge eventually proved to be somewhat limiting, says Gibbons—"only two or three social scientists among 4000 engineers and 'hard' scientists." In 1973, therefore, he accepted the opportunity to become director of the newly formed interdisciplinary Energy, Environment, and Resources Center at the University of Tennessee.

Completing the turn to policy

Leaving Oak Ridge wasn't a light decision, and Gibbons didn't make an irreversible move all at once. He took a leave from ORNL to accept the university post, including a physics professorship. But the pace quickened when the new Federal Energy Administration sought him out, within six months, to be director of its office of energy conservation.

Work in Washington held a special appeal, because of both its career merit for Gibbons and its implications for the Tennessee center later on. Consequently, he shortly found himself on leave from two institutions, commuting weekly between Knoxville and Washington, where the FEA quickly became a very visible pivot on which his career was turning. "I couldn't ever pay for the experience of those 12 months," Gibbons says today,

"I got to the FEA about six weeks before the OPEC oil embargo, and within 60 days I was in cabinet meetings. Our public education on energy efficiency became a firefight to constrain energy demand."





“Predicting the future isn’t the point. I’m talking about understanding future demand—that is, what things done now might affect the future.”

“but at the time it was more than I had bargained for.”

The intent, based on an idea from Nixon’s White House, was to bring about more efficient energy use by federal government agencies, as a model and showcase for the rest of the country at a time when summer gasoline and winter heating oil shortages were becoming a possibility. The actuality was very different. “I got to the FEA about six weeks before the OPEC oil embargo,” Gibbons recalls, “and within 60 days I was in cabinet meetings. Our low-level research program and public education on energy efficiency became a firefight to constrain all kinds of energy demand. I wore myself out in a very intense year and was relieved to be back in Tennessee in the fall of 1974. But it was a rewarding time,” he concludes, “in terms of what I learned and the network I’d become a part of.”

At Tennessee, Gibbons was well positioned to deal with public policy questions related to resource use. The Energy, Environment, and Resources Center was a mechanism for drawing on both university and nearby ORNL capabilities and applying them in contract studies for state and federal agencies. During the next four years Gibbons also served on several National Academy of Sciences studies, became a member of DOE’s Energy Research Advisory Board, and was on the advisory panels of two or three technology assessments for OTA. One particular National Academy role proved memorable and, he believes, very successful.

“I was asked to chair the panel on demand and conservation for the Committee on Nuclear and Alternative Energy Systems—CONAES,” Gibbons explains. “There were also panels on supply, environment, and economics. Our report on conservation pulled together much that had been done at Oak Ridge and elsewhere, making a compelling case for much lower demand growth—including the electricity sector—than people had ever thought about before. As a result, it was very controversial in 1978 and 1979, but it’s conventional wisdom today; people have gone beyond it.”

By the end of the 1970s, Gibbons’s major career turn was complete, marked by his return to Washington to become director of OTA. But he’s offhand about it, saying, “I’ve never had any feeling of precharting my course. Some people must always know where they want to be five years from now. I’ve always felt happy and fully consumed in what I’m doing *now*—and when other opportunities emerge, I’ll have a look at them. But I still don’t know what I want to be when I grow up!”

As was the case at Oak Ridge, Gibbons’s highly contemporary urban career today contrasts with his off-hours life in a traditional setting. But he talks about them in easy alternation, and you have the feeling that the governing attitude is the same, that Gibbons has his own unified field theory to live by.

For several years he and his wife lived on Capitol Hill, just three blocks from the OTA offices—not the family’s preference,

but as Mary Ann Gibbons said, “You’ll save two hours a day of travel, and I get an hour of it.” Three years ago, though, they moved to The Plains, about an hour west of Washington “on the foothills of the Blue Ridge, in horse country.” The choice of words alone suggests the atmosphere, but Gibbons adds a homely anecdote. “When I was too late at the pharmacy one night, they left a note in the window for me. ‘Your prescription’s at the restaurant,’ it said. ‘Go over and pick it up because you need it.’”

Advisory give and take

Gibbons is looked after by the governing board of OTA in Washington, as well as by the pharmacist in The Plains. His professional overseers are a scrupulously balanced joint congressional committee of six senators and six representatives, six of them Republicans and six of them Democrats, who convene every two or three months to review newly proposed assessment projects for OTA. One rule is consensus on the need; another is for OTA to live within its budget.

“They’re a real working board of directors,” says Gibbons. “They have to help me figure how to put 10 pounds of stuff into a 5-pound bag.” On a more serious note, he adds, “They’re very supportive, and without them I think OTA wouldn’t as clearly be seen as bipartisan, strictly bicameral, by other members of Congress.”

To keep that reputation and to avoid an insular view of technology issues that might compromise it, Gibbons welcomes

his advisory connection with EPRI. He underscores his personal interest in energy efficiency—"goods and services with the fewest undesired impacts from the use of energy and other resources." And he sees the Advisory Council also as an occasional forum for his Washington perspective on electricity policy matters.

An advisory role involves receiving information as much as giving it, Gibbons believes, saying that "one reason teachers teach is that it's a wonderful way to learn. These relationships won't work unless there's a two-way flow," he adds. "At OTA we've learned that the route to strength is by soliciting criticism and being pleased to receive it, not trying to avoid it. EPRI not only has the Council but has chosen to bring people to it who they know in advance are going to be pretty hard on them. It's a sign of wisdom and strength."

Even so, Gibbons feels that at times there's too little interaction between EPRI's Advisory Council and its Board of Directors. "I guess," he says, "catching your board is like catching our senior senators and congressmen. It's tough." He remarks that OTA's analogous advisory group has come up with a partial remedy—a brief but thoughtful communication to the agency's congressional board after each meeting. "I think this helps; it gives the board the comfort of knowing that the view from the distant star is being taken, that the advisers' perceptions are based on systematic observations."

Speaking more narrowly of technical reviews of the work done by EPRI and

OTA, Gibbons notes that the ultimate clientele of both organizations is the American public. "But if that's all we had, we'd be in trouble," he says. "They're so diffuse. Actually, OTA clients are specific congressional committees that have decisional authority. But we have the freedom to go beyond the specific questions a committee has in mind, to provide context and implications as well. And then we deliver to all of Congress."

As Gibbons sees it, EPRI similarly counts on an entire industry's collective need for a piece of research, not just the expressions of utility advisers. "But for both of us, specialized committee interest is advantageous in one important way: we're better assured that what we produce will be used." People see this, he adds, and it means that OTA and EPRI enjoy excellent "convening power"—they're able to draw on good people for help.

Advisory content

Hot topics come with the territory in Gibbons's work at OTA. One difficulty is institutional sensitivity, and Gibbons offers the example of the mixed reception and quick, high visibility of a short OTA paper—not even a full study—on space-based interceptors for the Strategic Defense Initiative. "That paper was one of the earliest to counter the administration position on what SDI could do."

Another difficulty is technical complexity. Here Gibbons cites two worldwide circumstances that are becoming part of EPRI's work context. "Global warming and intense international in-

dustrial competition—they're separate but congruent incentives for high energy efficiency and high productivity. But I think," he says insistently, "the demand side still receives less of EPRI's attention than it merits."

In part, Gibbons is talking about new technologies for electricity end use, especially those to replace liquid fossil fuels. Specialized electric vehicles are an example, he says, "but we're still not tackling the batteries as we should, and they're the heart of the issue in terms of the economics."

For the most part, though, he's referring to energy efficiency. "This is the question that's under-attended. Electric utilities and other industries are partners in the production of energy-related goods and services. We're after the minimum cost of the goods and services—not just selling electricity."

The basis for utility capacity planning is another subject that, in Gibbons's phrase, is under-attended. As recently as 15 years ago, he says, many utilities got into trouble because they overbuilt—"in effect using straight lines on semilog paper to project capacity needs, saying the past is the total predictor of the future. Some were nearly wiped out by that attitude," he adds. "But predicting the future isn't really the point. I'm talking about understanding what can affect future demand—that is, what things *done now* might affect the future."

The effort is difficult, Gibbons acknowledges, in part because the rules of the game have changed. "Commitment to deliver, to meet demand what-

“Energy is the reason we can live in big cities and occupy the Gulf Coast. It’s the reason we can travel and see relatives who, a hundred years ago, we’d leave and never see again.”





“Future generations won’t have the rich inheritance of natural resources that we have known. But we can leave them rich technological capabilities to offset that loss.”

ever it might be, was part of a social contract. Now we talk about a fully competitive climate. But it can’t be both, and I have a good deal of sympathy for the utility industry on that one.”

It’s a fine point whether only the rules have changed or whether it’s an entirely different game. Gibbons points to society’s identification of various external costs of electricity, such as air pollution, and its growing insistence on cutting those costs—and on internalizing them in the electricity price. “That requirement has come to rest at the feet of utilities because that’s where the most coal gets burned. They feel put upon, compared to other industries, but it’s not selective; it’s just that utilities happen to be the ones burning coal.”

Nuclear power—again, new rules or a new game or neither? As with capacity planning, Gibbons believes that some utilities have made serious management errors in choosing architect-engineers and in operating plants. “There’s a tendency to blame government regulation,” he comments, “but the fact is, there are utilities running nuclear plants that came in on time and on budget, under the same regulatory conditions.”

Putting these events and circumstances into context, Gibbons cites the overarching reality that marginal costs for utilities turned the corner several years ago. “When they’re going up for the first time ever in your professional career, and these other things are loading you, then it is a new ball game. And I think we’re all still adjusting.”

R&D for a conservator society

The conjunction of new economic and environmental imperatives for electric utilities is a clear mandate for R&D, in Gibbons’s view. Although his own daily work ranges far away from energy matters (which account for perhaps 10% of OTA’s effort today, in contrast to as much as 50% back in 1974), Gibbons clearly reckons energy as the central consideration in how our other resources and technologies can and should be applied.

If some of what he espouses carries a sense of mission, it’s because, as Gibbons says, “I’ve been fortunate in having the opportunity to gain an understanding of what energy means to us, to realize, for one thing, that energy is the reason we no longer have slavery. Energy is also the reason we can live comfortably in big cities; it’s the reason we can occupy the Gulf Coast in the summertime. And it’s the reason we can travel and see relatives who, a hundred years ago, we’d leave and never see again.”

Energy is not only a ubiquitous deliverer of goods and services; when used less thoughtfully than it might be, Gibbons admits, it’s also a principal source of pollution, notably in the very cities that it makes possible. He turns to the *OTA Joke Book* to make his point. “There’s a cartoon; two guys are standing on a New York street corner, and one of them says, ‘The way I see it, there’s a trade-off for everything. If you want a high standard of living, you settle for a low quality of life.’”

Gibbons puts his own spin on it. “I

think energy can enhance both, if we apply wisdom and thoughtfulness to how we produce, convert, and use it. That’s what I call the conservator society. But it’s not just energy,” he goes on. “It’s the whole flow of resources we consume. And my mission, I guess, is to help all of us realize that it’s quite possible to get what we want from our resources by using them more elegantly, in ways that minimize their net flow through society. We don’t need to have all the waste. We *do* need to look at *total cost*.”

Gibbons insists that energy isn’t a thing unto itself. Electricity, for instance, shouldn’t be seen as a cause of growth—“I differ strongly with people who say that the more electricity we have, the better off we are.” Gibbons argues that energy itself has no value; its value rests only in how we use it to provide goods and services. He muses, “I guess my dilemma is to be a technology optimist and at the same time understand the awesome ill effects that flow from misuse—that is, inefficient use—of resources. And also remain politically neutral!

“You know,” Gibbons says thoughtfully, “future generations aren’t going to have the rich inheritance of natural resources that we’ve known. But we can leave them rich technological capabilities to offset that loss. And this is where research comes in. It’s a key ingredient of our endowment.” ■

This article was written by Ralph Whitaker and is based on an interview with John Gibbons.

Environmental agencies and utility organizations from the United States and Canada representing key parties in the acid rain debate—are cooperating in the largest environmental measurement program in North American history. At field stations stretching from Florida to Quebec, researchers are collecting and analyzing winter snows and spring rains, sifting the air for gases and particles, and measuring winds, temperatures, and humidity levels. Flying through storm clouds in instrumented aircraft, cloud chemists are measuring atmospheric aerosols.

Researchers are also using sophisticated computer models to evaluate complex atmospheric processes and the acid rain phenomenon. The National Science Foundation is the sponsor of the program, which is a joint effort of the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the Canadian government.

The program is designed to provide a comprehensive picture of the acid rain phenomenon in North America. It will help scientists understand the sources of acid rain, how it is formed, and how it affects the environment. The program will also help to develop strategies to reduce acid rain emissions.

SEARCHING FOR ACID

How much acid rain will be produced? How will it affect the environment? To determine the answers to these questions, researchers are gathering field data for comparison.



all have a stake in the models' accuracy, representatives from each of these camps joined forces in a two-year field study to gather real-world data for evaluating the models.

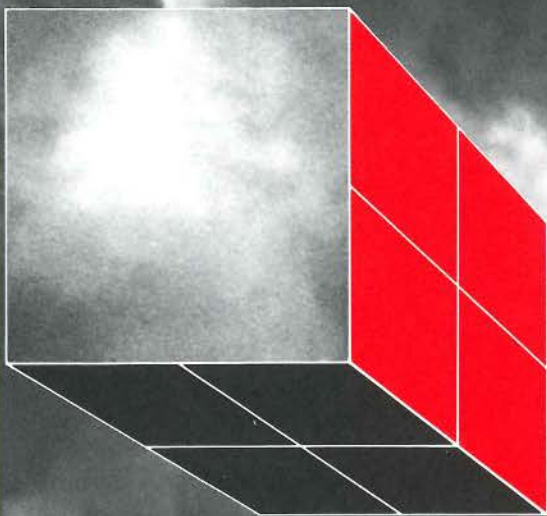
Given the complex atmospheric interactions that determine the fate of airborne pollutants, scientists would like to predict reliably where and in what form emitted material will be deposited. Until proven models are available, it is difficult to predict the outcome of a given strategy for controlling the emissions of sulfur dioxide (SO₂), nitrogen oxides, and hydrocarbons blamed for acid rain. Reducing

emissions by a given amount may not yield a proportional reduction in the acidity of precipitation. These uncertainties have created a dilemma for regulators trying to resolve the questions of when, where, and by how much emissions should be controlled for acidic deposition to become environmentally acceptable. The utility industry, whose coal-fired plants are targeted by legislation seeking to reduce SO₂ emissions, has a large stake in knowing just how specific plants contribute to acidic deposition in specific regions. Because of the high costs of cutting back SO₂, utilities want to be certain that the controls

would achieve the desired environmental benefits.

"There are only two ways to judge the efficacy of a given emissions control strategy," says Ralph Perhac, director of EPRI's Environmental Science Department and a member of the U.S. Inter-

Rain Models



agency Task Force on Acid Precipitation. "You can go ahead and do it—install control equipment and see what happens—but you may not get the results you want, and you'll have spent money that is lost irrevocably. Once you've put on a scrubber and find out it doesn't do what you want, you're stuck with a multimillion-dollar expenditure. The second way is to use a mathematical model, a long-range transport model, that allows you to judge what happens to deposition when you change emissions." Such a predictive ability would allow utilities to focus control efforts on plants whose emissions were indeed contributing to acid rain in sensitive ecosystems. A flexible, selective strategy that applies controls where they will do the most good could strike a balance between ecological and economic concerns.

This has been a major goal of the U.S. government's National Acid Precipitation Assessment Program. Congress launched NAPAP in 1980 to unravel the causes and effects of acidic deposition and to determine the costs and benefits of alternative control measures. NAPAP is overseeing the development of the Regional Acid Deposition Model (RADM) at the State University of New York at Albany and at the National Center for Atmospheric Research; funding for the development work is provided by the U.S. Environmental Protection Agency (EPA). In a parallel effort, the California firm ENSR (formerly ERT) is developing the Acid Deposition and Oxidant Model (ADOM) under funding by Canadian and West German environmental agencies and EPRI. When fed a data set that includes meteorological conditions and emissions from multiple sources, the models forecast how weather and atmospheric chemistry could interact to deposit the emitted material over broad regions. As policy-planning tools, the models are to be used to assess and analyze acidic deposition patterns as a result of changes in the simulated emissions mix. NAPAP plans to use RADM's predic-

tions in forming recommendations contained in its 1990 assessment report.

The accuracy of the models is clearly a central issue. If their predictions are to be accepted as reliable by policymakers, as well as the industries and consumers who will shoulder the economic burden of installing controls, the models ought to represent the acid deposition phenomenon with high fidelity. In addition, because the models will be used to expand our understanding of the dynamics of acid deposition, their accuracy is important to a broad cross section of the scientific community.

The concern for accuracy is especially significant because earlier attempts to model acid rain fell far short of their goal. In 1984 EPRI sponsored a project to evaluate regional air quality models and concluded that even the best of them were weak approximations of the real world they attempted to simulate. "We found from one earlier air quality study, the Sulfate Regional Experiment, or SURE, that our models, in terms of their predictive ability, had an average uncertainty of almost 100%," says Perhac. "Sometimes we'd be very close in our predictions, sometimes we'd be far off; but in four model runs comparing about 1000 pairs of calculated and observed data points, the average uncertainty was almost a factor of two, or about 100%. That's just not good enough to judge the efficacy of a control strategy."

RADM and ADOM are far more sophisticated than the SURE model, incorporating all the relevant chemical and physical processes in as much detail as possible. But our understanding of some of these processes is still incomplete, and the gaps have to be filled in with estimates, which may increase the uncertainty of the model results. Unless they are tested against real-world observations, there is no guarantee that RADM and ADOM will be any more reliable than their predecessors.

Recognizing that model predictions involve high stakes and large uncertainties, a panel of atmospheric scientists from government and private-sector organizations recommended in 1983 that the models be subjected to a rigorous evaluation by comparing their output against real-world measurements. Shortly thereafter, EPRI, EPA, the Atmospheric Environment Service of Environment Canada (EPA's Canadian counterpart), and the Ontario Ministry of the Environment cosponsored a series of workshops to determine the data requirements for such an evaluation and to plan a field study to collect the data.

The resulting joint study, launched last June and scheduled to run for two years, is gathering data on air quality, emissions, precipitation composition, and meteorological variables throughout the eastern United States and Canada. Three of the four initial sponsors (plus the Florida Electric Power Coordinating Group, which recently added its sponsorship to the study) have been independently operating their own precipitation-monitoring networks for some time. The model evaluation field study represents a milestone in atmospheric research in that the field stations composing the five networks will be coordinated under the direction of a bilateral steering committee representing all the organizations.

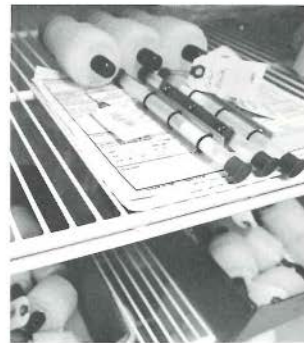
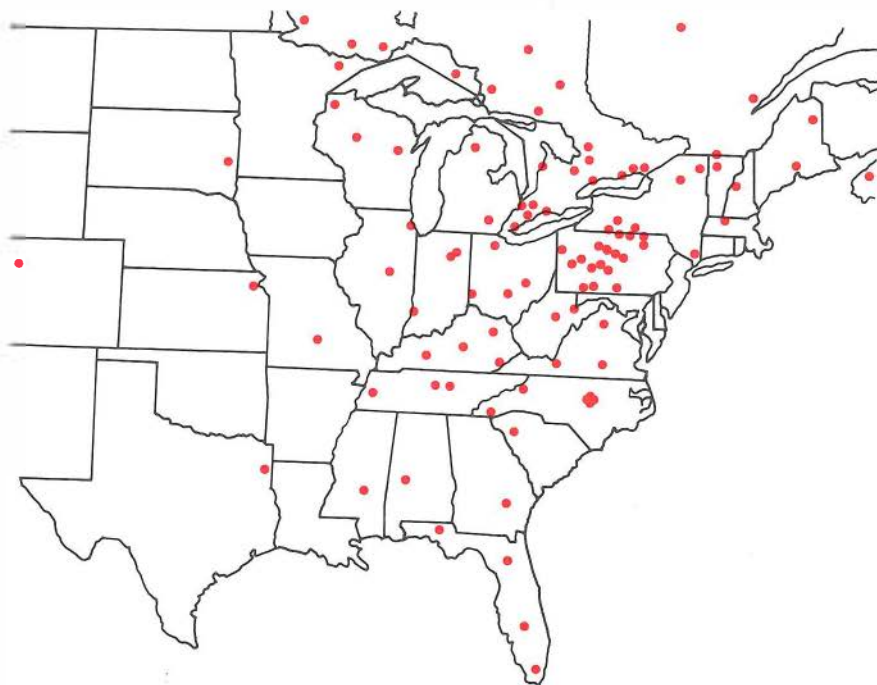
"If ADOM and RADM are to be accepted as reliable crystal balls, they must have a high degree of scientific credibility," says Alan Hansen, project manager for EPRI's portion of the model evaluation field study. "Our major objective is to provide a rigorous and technically credible evaluation of the performance of these models by pooling the resources of the groups operating the five monitoring networks as well as a dozen other organizations providing data."

Smoke and mirrors

Simulating the behavior of airborne pollutants, and then verifying the accuracy of the simulation, presents some inter-

Field Measurements

At more than 100 field monitoring stations distributed throughout eastern North America, researchers are gathering the full spectrum of chemical species that play a role in acid deposition. A typical field station is equipped to measure meteorological variables and sample wet precipitation, airborne gases, and particles. Instrumented aircraft gather atmospheric data that are used for diagnostic evaluation of the models' individual components.



esting challenges that are easily appreciated, even in microcosm.

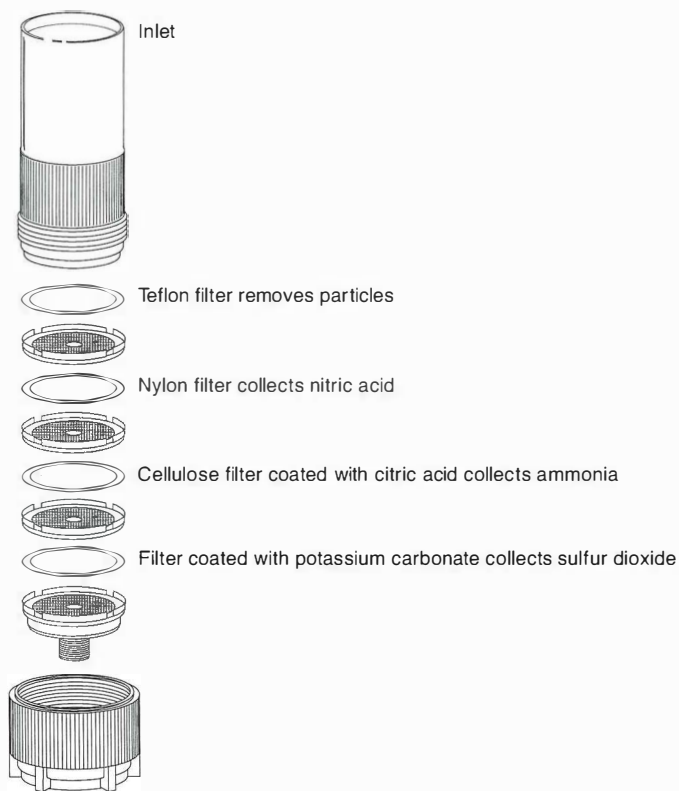
Even in the calm air of an enclosed room, the plume of smoke issuing from a cigar will rise in a steady stream for only a short distance before it starts to undulate and roil from faint turbulent eddies. Outdoors, a cigar plume encounters much greater turbulence, which disperses the smoke through a large volume of air containing water vapor and suspended particles. Carried on irregular air currents or wind, the combustion gases may travel some distance while chemically combining with the moisture and particles to create a new set of compounds. Depending on the weather, some of these may settle to Earth in dry form, some may be entrapped and brought down by falling raindrops. An elaborate interplay of air movements and chemistry thus governs where, in what quantity, and in what form the smoke is eventually deposited.

One cannot know precisely how the smoke will be transported, transformed, and deposited without measuring every detail of the process at an infinite number of points throughout the domain in which the process occurs. This is possible only in theory. Under the real-world constraints of money and time, the best one can do is take measurements at selected points and mathematically predict the average behavior of the governing processes to estimate where the smoke will land. Such estimates contain inherent uncertainties, even if many measurements are taken and the chemical and physical processes are accurately represented in equations. To determine if the mathematical representation mirrors what actually happens in nature, more measurements are required, this time to compare predictions against observations.

The formation, transport, and precipitation of acid rain obviously constitute a far more complicated phenomenon than the movement of smoke in air. Substitute an industrial smokestack for the cigar,

Sifting the Air

Particles and gases may be present in extremely low concentrations in some rural areas and are difficult to separate into individual chemical species. To capture and measure such scarce airborne substances, all the groups participating in the model evaluation field study are using samplers that draw large volumes of air through a series of selectively permeable filters. The first filter is porous Teflon, which traps particulate sulfate, nitrate, and ammonium while allowing gases to pass through. The second filter is porous nylon, which captures nitric acid as nitrate but allows sulfur dioxide and ammonia to pass through. The third filter is cellulose impregnated with citric acid, which captures ammonia. Sulfur dioxide is trapped on a fourth filter coated with potassium carbonate.



multiply it by hundreds of stacks spread across a thousand-mile region, add the emissions from hundreds of urban areas and from vegetation, expand the domain to most of eastern North America, and factor in the contribution of clouds, storms, and photochemical processes. "If utility stacks emitted sulfuric acid, the problem would be easier," says Perhac. "But they don't emit sulfuric acid, they emit sulfur dioxide, and before that adds to the acidity of rain it undergoes a variety of meteorological processes—transport, dilution, absorption in cloud water, and chemical transformations. So you don't have a simple relationship between what goes up and what comes down. What you have instead is a very complex relationship between the emission of one substance in one place and the deposition of another substance in a different place, and those two places may be a thousand kilometers apart. This all has to be built into the model."

The models are necessarily complex. Although RADM and ADOM differ somewhat in the way they simulate atmospheric processes, they are fundamentally similar. In their present configurations, the models divide the eastern United States and southeastern Canada—and the overlying atmosphere—into a three-dimensional grid 6 to 15 layers high, comprising thousands of individual parcels. In RADM these are 80 kilometers on a side, in ADOM 127 kilometers. The master models integrate the operation of four submodels, respectively simulating meteorology, cloud physics and chemistry, clear air chemistry, and dry deposition. The meteorological simulation is based on data from surface stations, airborne instruments, and satellites for such variables as wind, water vapor, cloud cover, temperature, pressure, and precipitation. The models then process these data to compute wind fields and weather conditions for a given time period—essentially producing a three-dimensional dy-

amic map of the atmosphere over eastern North America. The cloud, clear air chemistry, and dry deposition submodels take input data on natural and man-made emissions from point and area sources, along with chemical data on reaction rates, to predict transport and deposition as a function of weather. Capturing the interaction of these variables requires nearly a million lines of code running on a Cray supercomputer processing more than 200 million instructions per second.

Real-world measurements

Comparing model predictions against real-world observations requires detailed data sets for both input (emissions and meteorology) and output (wet and dry deposition patterns). Researchers have been gathering field data from many independently operated monitoring networks for more than two decades, but these networks were not designed with model evaluation in mind. Because different networks gathered samples at various intervals and used different sampling and analytical methods, the data sets obtained were generally not comparable. In addition, the focus of earlier studies was on obtaining samples of wet precipitation and measuring its acidity to determine acidification trends and ecosystem responses.

Because of the limitations of sampling instruments, relatively little quantitative information was gathered on dry deposition and atmospheric chemistry, especially the intricate chemical reactions that take place inside clouds. Since ADOM and RADM attempt to represent these reactions in detail, accurate measurements of gases and particles in very low concentrations are necessary, both for refining the models and for evaluating their performance. During the past several years, researchers have developed a battery of new instruments and sampling techniques that have helped them unlock some of the mysteries surrounding these processes, and that have

thus enabled model developers to represent the processes in computer code.

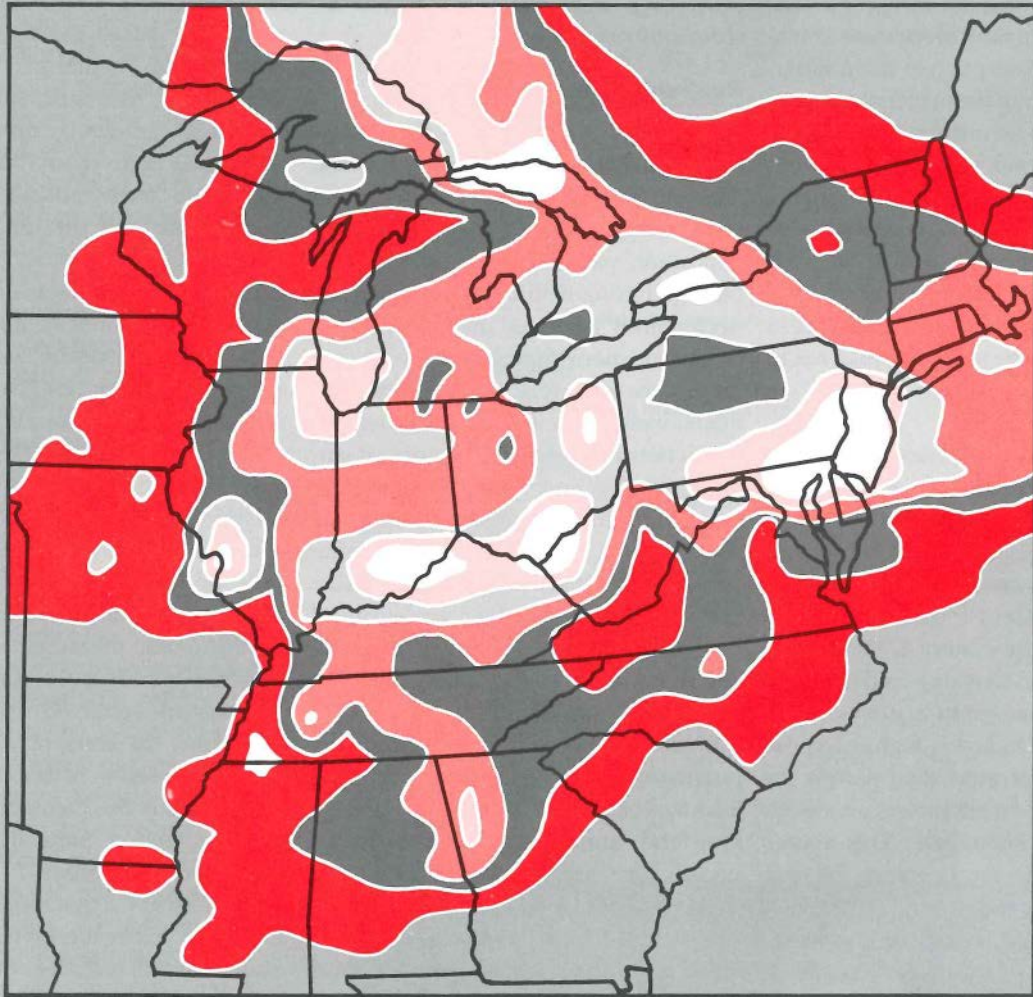
The combined network consists of more than 100 surface stations located in areas where their samples will not be influenced by local emissions sources. Each of the five networks has specific data-gathering objectives, but will use standardized measurement techniques and quality control procedures to ensure that all the data obtained are accurate and comparable. On a daily basis the stations will gather the full spectrum of chemical species that play a role in acid deposition. These include the gases SO₂, nitric acid, ammonia, nitrogen dioxide, ozone and peroxyacetyl nitrate, and the particulate forms sulfate, nitrate, and ammonium. Wet precipitation is being collected daily and analyzed for acidity, conductivity, and the major ions. Meteorological instruments mounted on 10-meter towers measure wind speed and direction, temperature, barometric pressure, and relative humidity.

Obtaining samples of gases and particles presents a challenge because many are present in such low concentrations—often less than one part per billion—that they could not be measured with conventional continuous analyzers, which take real-time measurements. To gather material in such low concentrations, the stations are equipped with filter packs that draw 20 liters of air per minute through a series of stacked filters that trap gaseous SO₂, ammonia, and nitric acid, as well as particulate sulfate, nitrate, and ammonium.

With EPRI's assistance, EPA is compiling an extensive inventory of emissions that will include those from 200 individual boilers identified as being the highest emitters in the eastern United States. The inventory will also contain estimated emission levels from other industrial sources, such as smelters, and from area sources, including motor vehicle traffic and windblown dust. Supplemented by extensive emission inventories compiled for previous years, EPA's

Mapping the Patterns of Acid Deposition

The RADM and ADOM models simulate the complex interaction of weather and chemistry to depict acidic deposition patterns over broad regions. To determine whether such simulated patterns accurately represent what happens in the real world, field researchers measure actual deposition in as many points as possible. But because the number of measuring stations is limited by economics and practicality, scientists must use statistical methods to interpolate deposition values between field stations. This RADM display depicts sulfate wet deposition over a 66-hour period.



and EPRI's data will be used to calculate emission levels on an hourly basis over the entire two years of the field study.

Defining the uncertainties

The models depict deposition patterns over broad regions, while the field stations take point measurements. "The models have more than 3000 surface grid cells, but we have only just over a hundred stations—so we're sampling a very small fraction of the modeling domain," says Hansen. "That means we have to interpolate between measurement points to get a smooth picture that compares with the smooth picture the model depicts." One objective of the study is to answer the question of how well measurements at a single station represent the conditions of a model grid cell 80 to 127 kilometers on a side. This will be addressed by siting two or more clusters of stations within individual grid cells.

The model evaluation team is also using a statistical interpolation technique called kriging to estimate deposition values between field stations, as well as to estimate the uncertainty associated with those interpolated values. "There will inevitably be a difference between the model calculations and the observed values," says Hansen. "Understanding the reasons for the difference between calculations and observations is an important part of a credible model evaluation. The key is understanding how the uncertainties in measurement, in the interpolated values, and in the model all contribute to the deviation between predictions and observations." Once you have a handle on the uncertainties in the model and the uncertainties in the observations, Hansen goes on, if the agreement between predictions and observations is within the combined uncertainty, "you've done a good job—that's as well as you can expect the model to perform."

The bulk of the deposition and emissions data gathered during the study will be used to operationally evaluate the model calculations with field observa-

tions. "Operational evaluation answers the question, is the model giving the right answers?" says Hansen. "It is possible, however, that the model prediction agrees with the observation, but that the agreement is fortuitous. It may be due to chance or compensating errors, not because the science is correctly represented." Whether the model is giving the right answer for the right reason is judged by another type of test—diagnostic evaluation, which examines whether or not a model's individual components are working correctly, especially in simulating critical atmospheric processes.

Gathering data for diagnostic evaluation is the objective of two 6-week intensive measurement campaigns. Instrumented aircraft gather atmospheric samples to yield vertical profiles of emission concentrations, while a few specially equipped surface stations collect air quality data at shorter sampling intervals and for chemical species not measured routinely. Owing to limitations of technology and funding, however, less emphasis is being placed on diagnostic evaluation than on operational evaluation, and researchers expect that many more than two intensive measurement campaigns will be needed to really understand the extent to which individual components of the model will have to be redesigned.

"If the models don't give us answers for the right reasons, they could give us the wrong answers for a different set of input conditions," says Peter K. Mueller, manager of EPRI's Air Quality Studies Program. "But we won't know whether they will or will not if we couldn't check the mechanisms underlying the calculations. The intensive measurements will give us some information about whether or not the mechanisms are properly represented, but we won't get enough information with the resources that are being made available."

Despite the limitations imposed on the intensive measurement campaign, the

comprehensive two-year data set generated by the field study will illuminate and clarify many of the unknowns facing acid rain researchers, and the models themselves hold considerable potential as tools to promote scientific understanding. "These models are not just acid rain models, they are air quality models," says Mueller. "They can help us understand how human activity influences the atmosphere and what kind of behavior by human populations is necessary in order to maintain a habitable planet. With some refinement they can help us address other atmospheric issues now emerging as a result of an expanding population." These issues include human health, visibility, proposals to control ozone in the lower atmosphere, and the contribution of carbon dioxide, other greenhouse gases, and particles to climate change.

Acid rain is an emotionally and politically charged issue, and perceptions and politics may overshadow the efforts of scientists working to advance our understanding of a complex phenomenon. Developing a national policy involves difficult decisions; for more than a decade, EPRI has sponsored research in the atmospheric and ecological sciences so those decisions can be well informed. "We're trying to provide the decision makers with the information they need to come to rational conclusions," says Hansen. Scientific information will not be the only basis for choosing an acid rain policy; such a choice will also involve value judgments on how regional economics relate to national, or global, environmental concerns. But science can help us to better understand the nature and extent of the problem and to objectively evaluate the consequences of our actions. ■

This article was written by David Boutacoff. Technical background information was provided by Ralph Perhac, Alan Hansen, Peter K. Mueller, and Mary Ann Allen, Environment Division.

TECH TRANSFER NEWS

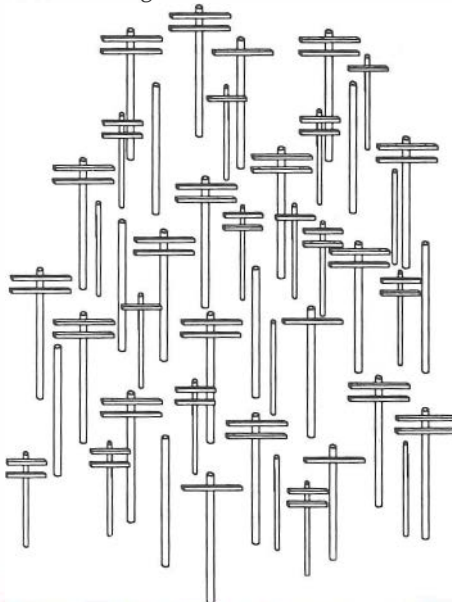
Pole Tester Reduces Replacement Costs

More than a dozen utilities are now enjoying substantial cost savings related to wood pole repair and replacement by using PoleTest,* a portable ultrasonic inspection device developed by EPRI that can more than double the accuracy of conventional wood pole examination techniques. The device can eliminate needless or premature pole replacement, thereby dramatically extending the useful life of wood poles and in some cases saving millions of dollars in replacement costs. "More than 200,000 poles are replaced each year," EPRI Project Manager Paul Lyons says. "To extend the useful life of a third of these—65,000 poles—would save utilities more than \$200 million a year."

At Indianapolis Power & Light (IP&L), inspectors used PoleTest on 600 Douglas fir poles that suffered from premature groundline-bending failures caused by a deep incising process. IP&L inspection personnel collected data above the incised zone (5 to 7.5 feet above groundline) to determine whether to reinforce or replace a pole. PoleTest results indicated that 430 poles had sufficient strength

above the incised zone to withstand reinforcement and repair. "PoleTest strength information helped us make a cost-effective maintenance decision of groundline reinforcement/encasement in lieu of pole replacement," says IP&L staff forester Mike Baldwin. "We estimate savings in the range of \$1 million."

In another application, Omaha Public Power District (OPPD) used PoleTest to evaluate a 30-mile portion of a 161-kV transmission line. Because the device's strength predictions enabled selective replacement of a small number of poles in lieu of wholesale replacement, OPPD was able to defer about \$2.7 million in replacement costs for 10 years. PoleTest can also be used to assess lightning damage. Bonneville Power Administration (BPA) evaluated 11 lightning-damaged poles and saved \$20,000 when it was determined that four of them could be salvaged. Both BPA and OPPD plan to use PoleTest on a regular basis to evaluate in situ strength of wood poles. Other utilities using PoleTest include Tampa Electric, Arizona Public Service, Duke Power, Puget Sound Power & Light, Iowa-Illinois Gas and Electric, Western Area Power Administration, and Carolina Power & Light.



Unlike traditional nondestructive evaluation methods, which use poorly correlated strength-stiffness relationships to assess wood pole strength, PoleTest takes ultrasonic data directly from the pole being tested and correlates these findings with full-scale strength test data. A digital readout displays the most likely bending strength of the tested pole.

The system's comprehensive internal program allows utilities to test virtually every pole in a transmission line to a high level of confidence. Analysis takes three to five minutes. ■ EPRI Licensee: Engineering Data Management, Inc., Fort Collins, Colorado. EPRI Contact: Paul Lyons, (817) 439-5900

Handbook for Plant Water Management

Faced with environmental restrictions on wastewater discharges and increased competition for high-quality makeup water, many utilities are recycling and reusing their in-plant water. This process of integrated water management requires accurate monitoring and control of process stream flows and compositions. At most plants, however, water management instrumentation is insufficient for proper monitoring and control of key process parameters.

Instrumentation Handbook for Integrated Power Plant Water Management (CS-5873) is a new EPRI-developed resource that can help utility staff in the design and operation of integrated water management systems. An overview describes plant systems and essential considerations. Separate sections focus on the primary measuring instrumentation for water flow, level, density, temperature, pressure, and several chemical parameters. The handbook also includes a bibliography of instrumentation references.

■ EPRI Contact: Wayne Micheletti, (415) 855-2469

*PoleTest is an EPRI trademark.

Lightning Network to Extend Nationwide

Over 50 member utilities and service groups east of the Mississippi River rely on real-time data on lightning flashes in their service territories. This storm-tracking capability will be expanded in 1989 to offer assistance to utilities nationwide in managing their responses to lightning storms and in designing surge protection schemes for distribution lines. The data come from a network of lightning flash locators operated at various locations around the country by EPRI's contractor, the State University of New York at Albany. The number of locators will be increased from 80 to 120 early next year.

The cost of repairing lightning damage to transmission and distribution systems is estimated at \$50 million a year, and in some regions up to 40% of customer outages are attributable to lightning. Some of this damage is inevitable, but some can be prevented; moreover, much of the damage that does occur can be repaired more quickly and efficiently if utilities know how often, where, and when lightning strikes. They can obtain this information by subscribing to the detection service. To learn when an approaching storm front reaches the borders of their territory, for example, system engineers can watch a screen or can set a monitor that activates a buzzer when the first flash of lightning occurs within a specified geographical area.

In order to access and analyze the data, a utility must have an IBM PC or a remote display processor provided by EPRI. With an investment of less than \$10,000 in equipment, a utility within the monitored area can obtain coverage through an easy-to-use and inexpensive satellite hookup. The average annual cost to an EPRI member for the hookup is about \$7000. "We used to spend that much in holding crews overtime unnecessarily in one or two storms," says Andrew Dodge

of Baltimore Gas & Electric, "so the network is definitely a worthwhile investment for us." ■ EPRI Contact: James Mitsche, (415) 855-2298. For videotape, contact Susan Rapone, (415) 855-2147

Guidance for Cofiring Refuse-Derived Fuel

The declining availability of sanitary landfill sites has increased interest in energy recovery from municipal refuse. One technological option is cofiring refuse-derived fuel (RDF) with coal or oil in electric utility boilers. However, because of unresolved problems with the economics of RDF production and the use, in some cases, of boilers not suited to RDF cofiring, five of nine U.S. utilities engaged in RDF cofiring have discontinued their cofiring operations. Now, though, utilities can turn to a new reference, *Guidelines for Cofiring Refuse-Derived Fuel in Electric Utility Boilers* (CS-5754), for guidance.

Volume 1, an executive summary, provides an overview of waste-to-energy and RDF-cofiring technologies. Volume 2, engineering evaluation guidelines, summarizes key factors to consider when evaluating a proposed RDF-cofiring project and addresses the impact of cofiring on power plant performance, operations, and economics. Volume 2 also presents the RDF Cofiring Boiler Performance Model, or RDFCOAL, a micro-computer-based spreadsheet program. Volume 3 contains appendixes that provide supplemental design, operating, and cost data.

Overall, the guidelines will help utilities identify those units most amenable to RDF. They will also be useful to utility engineers in evaluating and responding to community proposals to burn municipal refuse in plant boilers and in assessing the significance of the adverse impacts of RDF cofiring. ■ EPRI Contact: Charles McGowin, (415) 855-2445

Helping Utilities Market Cool Storage

Cool storage can alter customer loads to the mutual benefit of customers and utilities. Many utilities look to commercial cool storage technology to improve load factors and reduce capacity requirements and generation costs while providing their customers with cheaper, more reliable air conditioning service.

Customers have been slow to accept the technology, however, and utilities have to understand the barriers to customer acceptance and to adopt marketing strategies to offset them. To meet this need, utilities can turn to the *Cool Storage Marketing Guidebook* (EM-5841), a collection of detailed case studies and step-by-step procedures for creating and implementing marketing programs that effectively promote commercial cool storage.

The guidebook provides detailed assistance on how to develop, implement, and evaluate an effective marketing program and discusses the operations and benefits of cool storage technologies. In addition, the guide describes the experiences of four utilities with cool storage marketing programs (San Diego Gas & Electric, Jersey Central Power & Light, Texas Utilities, and Southern California Edison), detailing their strategies, results, and lessons learned. Also discussed are processes and criteria for commercial-sector decision making, common barriers to acceptance of the technology in the commercial sector, and effective marketing techniques for overcoming them. ■ EPRI Contact: Ronald Wendland, (415) 855-8958, or Larry Lewis, (415) 855-8902



*Plant Performance Improvements***BWR Pipe Repair and Replacement**

by Wylie Childs, Nuclear Power Division

Intergranular stress corrosion cracking (IGSCC) of stainless steel recirculation piping in boiling water reactor (BWR) nuclear power plants has been a major concern for the past 14 years. Virtually all of the originally installed piping proved vulnerable to cracking in the heat-affected zone of welds. Substantial time and resources have been invested in efforts to identify the breadth of this problem and to develop practical solutions for it. EPRI has been instrumental in coordinating these efforts and in heading up others undertaken to provide workable options for dealing with weld-area IGSCC. The options developed as a result of these programs are now incorporated into the latest regulation guideline, NUREG 0313, Rev. 2. Work remains to be done in applying these techniques, but most utilities have already used one or more of the proposed countermeasures.

The most obvious solution to cracking in

Type-304 and Type-316 welded stainless steel piping is to replace these standard stainless steel alloys with an alloy that is more crack-resistant. An extensive laboratory testing program demonstrated that low-carbon stainless steels with controlled minor-element chemistry and fabrication procedures offered far greater IGSCC resistance; examples are nuclear grades 304, 316, and 347.

Replacing piping in a nuclear power plant is, however, time-consuming and costly. The replacement work can take a year to complete and can cost as much as \$50 million, excluding the cost of plant downtime and of substitute power. Moreover, technology and guidelines had to be developed to ensure the greatest corrosion resistance in the new piping and the cost efficiency of the installation procedure itself. Guidelines were also needed to assist utilities in preparing purchase specifications for the new alloys.

EPRI's Nondestructive Evaluation (NDE) Center undertook a major program—with the support of the Boiling Water Reactor Owners Group (BWROG)—to provide help to utilities in repairing and replacing recirculation piping. Early on, guidelines were published for writing chemistry and process-control specifications for the new pipe materials.

The development of machining and welding procedures presented other problems. For example, as much automation as possible was necessary in order to minimize personnel exposure to radiation. The use of automatic welding techniques made it necessary that the machining done in preparing the joints for welding be much more accurate than is required for conventional welding. Some portable machining equipment was available, but its appropriateness had to be evaluated in terms of each task, particularly because machining the tougher stainless steels imposed additional requirements on the tooling. Limitations of the available machining equipment were noted, and some manufacturers responded by modifying their products accordingly; as a result, improved tools were made available to utilities.

Additional and unforeseen complications were introduced by the use of automated gas-tungsten arc welding, the process universally used for remote and semiremote welding. Used with conventional welding schedules, gas-tungsten arc welding produces significantly higher distortion and residual stresses than occur in the shielded metal arc and submerged arc welds used in the original piping installation. Consequently, new welding procedures were developed that had lower energy densities

ABSTRACT *Cracking in the heat-affected zone of welds in boiling water reactor piping has been a significant factor in unscheduled nuclear plant downtime. In order to help utilities minimize the operational effects of weld cracks, certain techniques and guidelines are now employed. Options include, in addition to cost-efficient pipe replacement procedures, weld overlays to strengthen welds in which cracks are detected and processes for relieving weld-induced stresses in both new and in-service piping.*

and that required less energy to deposit a given amount of weld metal. Not only was there a major reduction in distortion and residual stress, but the installation time and cost were reduced. The time and cost savings made the process attractive to utilities and their piping contractors, and the reduced residual stress should enhance the corrosion resistance of the piping.

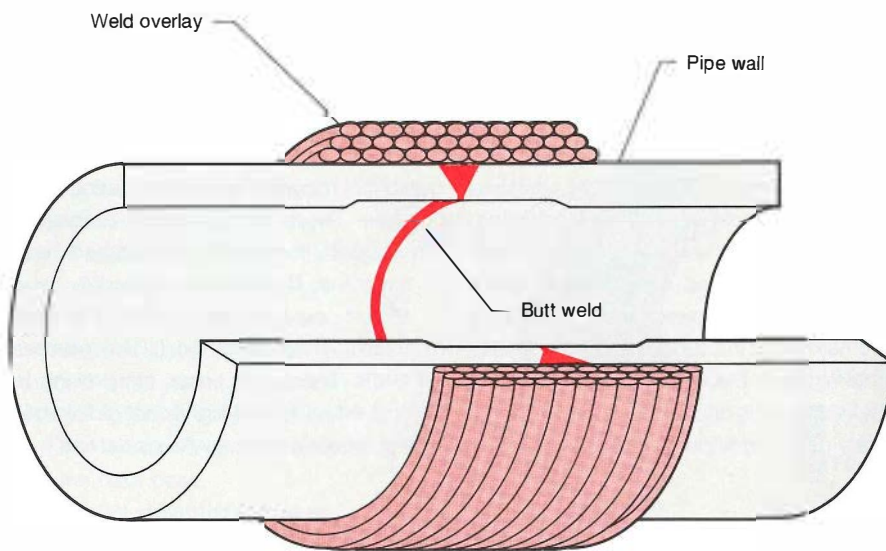
Recirculation and other piping systems at eight domestic BWR plants have been replaced with nuclear grade 316 stainless steel piping, and replacement is in progress at another plant. The NRC has recognized the acceptability of these replacements by waiving the augmented inspection requirements earlier imposed on these installations because of the threat of stress corrosion cracking.

Because of the cost of replacing existing plant piping with new-alloy piping, other solutions to the cracking problem in the heat-affected zone of pipe welds have been sought. In weld overlay repairs, for example, a welded joint in which there are indications of a crack is overlaid with several layers of corrosion-resistant weld metal (Figure 1). This overlay repair can be carefully designed to provide the same overall strength as that of the original weld. Seen at first as only a temporary solution, useful primarily in keeping a plant running until the next outage, when the potentially defective piping could be replaced, the weld overlay technique has been so refined and accepted that some overlays have been approved for up to four cycles of operation. And still further time extensions are likely for these repairs.

A key element in the greater acceptance for long-term use of the weld overlays has been the ability to inspect them for any further crack growth. The EPRI NDE Center was primarily responsible for developing technology to ensure NDE inspectability of the overlays. In addition, NRC acceptance of the technology has facilitated its use as a longer-term remedy.

Although weld overlays were originally intended for application to only stainless steel joints, it has been found desirable to place

Figure 1 Weld overlay repair for a cracked weld joint. The overlay repair is just as strong as the original weld. This alternative to costly pipe replacement has in certain instances been approved for as many as four cycles of operation.



them over safe-end-to-nozzle welds. This introduced a new complication, since welding onto the low-alloy steel nozzle would normally require a local postweld heat treatment. Fortunately, EPRI had earlier developed a temper-bead repair procedure in which a gas-tungsten arc welding process is used instead of the costly, time-consuming conventional postweld heat treatment (RP1236-1). In anticipation that the process might be needed for a safe-end-to-nozzle weld overlay, the EPRI temper-bead process was further developed for this application in conjunction with Georgia Power. The process was first used in replacing pipes at the Vermont Yankee station; subsequently, it has been used at two other plants.

Welds on stainless steel pipes cause residual tensile stresses on the adjacent inner surfaces of the pipes. Because these welding-induced stresses are major factors in IGSCC of stainless pipes, various post-welding procedures have been developed in efforts to relieve them.

The first widely used stress improvement technique was induction heating stress improvement (IHSI), in which the outer portions of a pipe weld are heated by induction while water is used to cool the inside of the pipe. The plastic strain of the metal caused by the

sharp thermal gradient across the pipe wall redistributes the stresses, either greatly reducing the residual tensile stresses or even converting them to compressive stresses, and thus materially improves corrosion resistance.

In a more recently developed method—the mechanical stress improvement process (MSIP)—a compressive strain is applied to a pipe a short distance from the weld; as a result, residual stresses at the weld and in the heat-affected zone are reduced.

These stress improvement processes are especially attractive when applied to new piping in which there is no cracking. In the case of in-service piping, however, it is not always possible to ensure that cracking was not under way before the stress improvement process was applied. This limitation is recognized by the NRC, which gives fewer inspection credits if the treatment is done after piping has been in service two years than if pipes are treated before being put into service.

In some plants, replacement pipes made of more highly corrosion-resistant alloys have also been stress-treated to further improve their resistance to corrosion; in other plants, the stress treatment has been ap-

plied to forestall or prevent the need for future pipe replacement and to take advantage of the NRC-allowed inspection credits for treated in-service systems.

Since as low as reasonably achievable (ALARA) radiation goals are becoming increasingly important to the owners of BWR plants, attention has been given to minimizing the recontamination of newly replaced piping. Techniques for reducing contamination are available and have already been used by many utilities (e.g., Northern States Power, Nebraska Power, and Philadelphia Electric) to limit the surface area exposed to contamination. Electropolishing component inner surfaces is one such technique that is widely used. Additional benefits are gained

by subsequent preoxidation to minimize the incorporation of contaminants in the new oxide formed during operation. Where both techniques have been used, subsequent contact radiation levels have been reduced by factors of 4 to 6.

Chemical decontamination of piping systems has also been widely used to minimize personnel radiation exposures during plant outages. The decontamination processes have been thoroughly researched and documented. By far the most widely used in recent outages has been the low-oxidization-state metal ion (LOMI) process for BWRs. These processes are proving to be cost-effective and significant aids to utilities in meeting their ALARA objectives.

Finally, the lessons learned through these piping replacement and repair efforts have been documented and made available to BWROG members. During one utility's planning for a recent piping replacement, the entire engineering staff reviewed the documents before proceeding with the work. As a result, the job was done better and at significantly less cost.

December 1988 calls an end to this very successful program. EPRI will continue a small program through the Repair Applications Center of the EPRI NDE Center in order to provide a focus for maintaining and making available to BWR utilities assistance with the applied technology developed over the course of the major program.

Distribution

Reducing Lightning Damage and Outages

by James Mitsche, Electrical Systems Division

During an average year in the United States, lightning causes an estimated \$50 million in damage to power lines, transformers, and other electric utility equipment. In regions like the U.S. eastern seaboard, lightning may be the cause of 45% of power outages.

With millions of miles of transmission and distribution lines crisscrossing the nation, some of this lightning damage is inevitable. But some of it can be prevented, and much of the damage that does occur could be repaired more quickly and safely if utilities had a better understanding of where and when lightning is most likely to strike.

Thus was born the Lightning Detection Network (LDN). It was designed to gather long-term data that could be used to map the frequency, location, and severity of lightning throughout the United States. Over time, such a data base will help utilities refine their decisions on how much surge protection equipment to buy and where to install it. In the near term, however, the LDN is being used by participating utilities as a

storm-tracking service. By accessing the LDN computer in Albany, New York, utilities can continuously monitor the location of lightning as it approaches and passes through an area. This knowledge helps them decide when and where to mobilize repair crews before the storm arrives. Those utilities already subscribing to this service

(\$7000 a year for data communications and other nonresearch costs) find that it pays for itself very quickly in more efficient use of manpower and in more rapid restoration of customer service following lightning-related outages.

The techniques used in the LDN were first developed in the late 1970s. Some of the

ABSTRACT *Lightning-related damage costs utilities an estimated \$50 million a year. The Lightning Detection Network, developed by EPRI, provides real-time storm tracking while collecting data that will make it easier for utilities to refine their protection strategies according to regional climatic conditions. Two new projects are aimed at helping utilities select the most cost-effective lightning protection equipment for their distribution systems.*

earliest applications were in the western states (by the Bureau of Land Management and the U.S. Forest Service) to aid in forest and range fire detection. In 1979 Tampa Electric installed a lightning detection system as a part of a DOE-sponsored study on the effects of lightning on distribution lines. By 1983 the National Science Foundation and NASA had jointly funded the installation of eight monitoring stations along the East Coast. Recognizing the potential value of such a network to utilities, EPRI funded a program to expand the system. The LDN now operates throughout the entire continental United States except for parts of five Upper Plains states. By the end of 1988, these states will also be monitored.

Each station consists of an antenna and a modest amount of electrical hardware compact enough to fit into a small trailer. The stations, each with a nominal range of about 150 miles (240 km), are linked by satellite to a data-processing center at the State University of New York at Albany. One hundred and twenty stations are needed to cover the continental United States. The Albany center has recorded nearly 30 million lightning flashes since 1983, archiving the information for later analysis and compilation.

LDN data are plotted on maps displayed on computer screens. The maps show lightning flashes detected in the previous hours and are continuously updated so that newly detected flashes show up in real time. Using this information, a utility can quickly respond to outages and can avoid unnecessary repair crew overtime due to imprecise weather forecasts. Monitoring the storm also helps the utility determine when repair crews can safely repair damage.

The network has also produced other benefits. Data from the monitoring stations, for example, are used to construct annual contour maps of the frequency of lightning flashes in the United States (Figure 1). These maps help utilities determine how much lightning protection is needed in different areas. When the maps showed that a 69-kV aerial line planned by Philadelphia Electric would pass through an area of relatively high lightning frequency, the utility pro-

graded its lightning protection on that line.

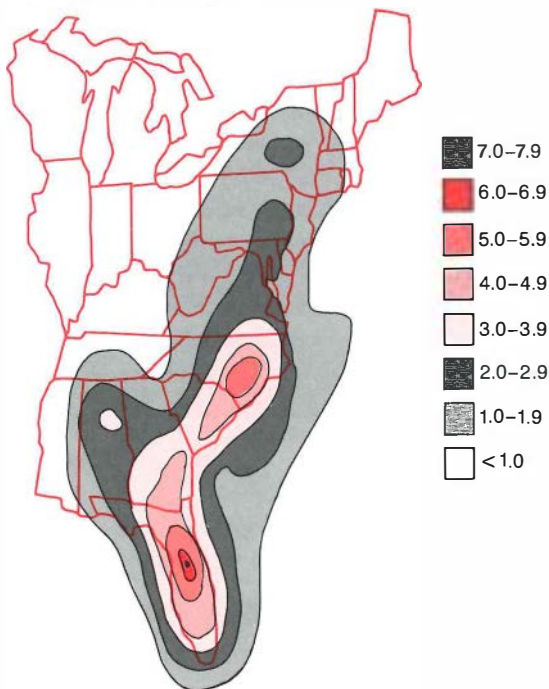
Multiplicity and peak current data also help utilities improve equipment protection schemes. For example, if most of the lightning flashes in an area have one or two strokes of relatively low current, less expensive surge arresters would protect the distribution equipment. On the other hand, in an area of severe lightning, heavy-duty arresters would be needed. Data collection is planned for 11 years, the natural cycle of lightning activity, to ensure that annual variations do not bias the data base.

The LDN determines where lightning strikes and how often, but it cannot determine how well distribution lines can weather the storm. In a second EPRI project, researchers developed a current and voltage-surge recorder (RP2542). Mounted on a distribution pole, the instrument records the current and voltage magnitudes and waveforms caused by lightning. The recorder's ability to measure the very infrequent, very fast surges caused by lightning was recently demonstrated successfully in triggered lightning tests sponsored by NASA at Cape Canaveral, Florida.

These measurements help determine how lightning affects distribution lines. In St. Petersburg, Florida, 80 recorders were installed, and 50 recorder-years of service were completed on a portion of the Florida Power Corp. distribution system. Data collected over one summer indicate that direct lightning hits are rare, but that nearby strikes are very frequent and cause potentially damaging voltage surges in the distribution lines.

Voltage surges caused by nearby strikes are smaller than those caused by direct strikes; this has important implications in sizing surge arresters. A common form of distribution line protection equipment, surge arresters function only when the volt-

Figure 1 This map of annual ground flash density shows lightning flashes per square kilometer. The Lightning Detection Network collects data around the clock 365 days a year to generate such maps for regions throughout the continental United States.



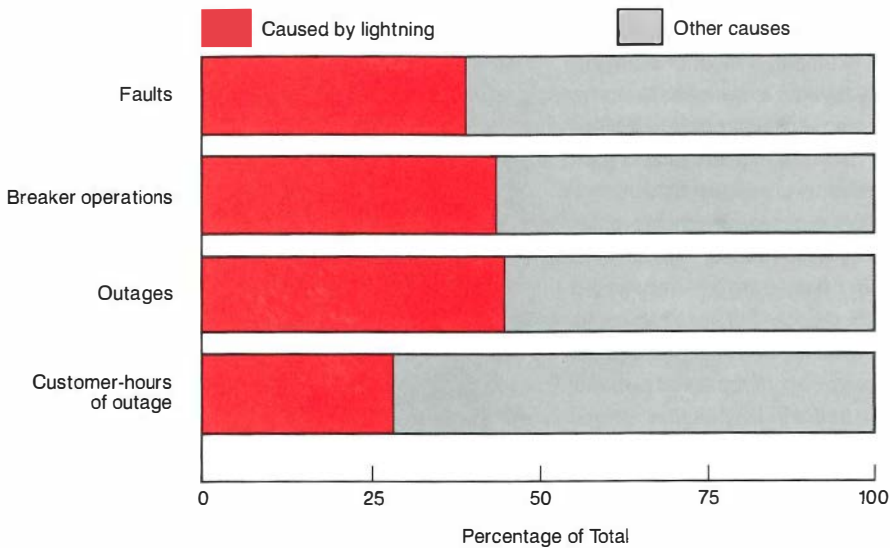
age in the line exceeds a preset value. As a result, an arrester designed to protect equipment from direct lightning strikes may not be triggered by the surge resulting from a nearby strike. Ongoing data collection and analysis will examine the potential long-term effects on distribution equipment of large numbers of these smaller voltage surges.

These and other data were also used to determine what portion of total faults and outages were caused by lightning in the monitored area (Figure 2). Unavailable before this study, these kinds of data will help utilities decide how to allocate resources to reduce outages.

EPRI work is planned that will address the engineering aspects of lightning protection; these projects will help utilities reduce lightning damage by improving the design of distribution poles and lightning protection equipment.

Because a pole's insulation character-

Figure 2 Impact of lightning on a portion of Florida Power Corp.'s distribution system. Data were collected over 18 months. Fault, breaker, and outage data were normalized by number of events per kilometer of line per year; customer outage hours were normalized on an annual basis. Such data will help utilities better understand system reliability.



istics affect its ability to withstand lightning strikes, the basic impulse level (BIL) of the pole is a key design parameter. Although calculating this level is straightforward for simple homogeneous structures, it is difficult for complex structures in which several insulation materials are used. In 1989 EPRI will publish a handbook for calculating the BIL of composite distribution structures. This project will help utilities improve the design of power poles to protect against lightning (RP2874).

EPRI has also issued a request for proposals for the development of IBM PC-compatible software to aid lightning protection engineering. This easy-to-use software will embody lightning data, protection design methods, protective equipment characteristics, and tutorial information. It will be compatible with other EPRI software and provide a complete set of analysis tools.

Demand-Side Planning

INDEPTH Industrial End-Use Planning Methods

by Ray Squitieri, Energy Management and Utilization Division (Customer Systems Division)

Utilities have traditionally employed time-trend or simple econometric modeling techniques, or customer interviews, for forecasting the industrial use of electricity. Those forecasting techniques were suitable during periods of steady economic growth and relatively stable patterns of energy consumption. However, they cannot explain how changes in the environment—and associated changes in industrial equipment, technologies, or production processes—can affect industrial-sector electricity use. Consequently, many utility forecasts produced with those techniques have failed to provide accurate assessments of industrial demand.

INDEPTH, a computer modeling tool developed by EPRI, currently enables utility planners to accurately analyze and forecast industrial electricity consumption. The INDEPTH system enables utilities to (1) make

long-term econometric forecasts of electricity use for all or selected parts of the manufacturing sector in their service areas; (2) examine in detail the energy consumption of those industries and processes most important to their service areas; and (3) investigate those uses of electricity, such as motors and process heat, that are most relevant to marketing and demand-side programs.

INDEPTH overcomes the shortcomings of early industrial forecasting models by combining econometric techniques with equipment and process models. Through this combination INDEPTH estimates the way changes in energy prices and industrial output will affect industrial-sector electricity sales. It also estimates how sales will be affected by the use of new equipment, technologies, and processes, and by the implementation of utility demand-side manage-

ment programs. Information generated by INDEPTH can also be used for marketing and planning and for industrial load shaping. Table 1 presents an overview of the INDEPTH system.

How INDEPTH works

INDEPTH uses a hierarchy of three modeling levels: econometric models, process models, and equipment models. Each successive level provides increasingly specific information about industrial-sector energy consumption. Users choose the level that best suits their particular forecasting needs, their data, or the economic characteristics of their service area.

The level 1 econometric models forecast industrial electricity consumption for an entire service area. There are models for each of the 20 two-digit Standard Industrial Classification (SIC) industries in the man-

Table 1
INDEPTH END-USE PLANNING SYSTEM

Modeling Level	Utility Use	Level of Industry Detail	User Input	Forecast
1. Econometric	Forecasting	20 industry groups (SIC 2-digit)	Product forecasts Energy prices	Kilowatthour sales
2. Process	Forecasting Market planning	10 major industries (SIC 2-, 3-, 4-digit)	Product forecasts	Kilowatthour sales Kilowatthour intensity Technology cost comparisons
3. Equipment	Market planning Marketing Demand-side planning	30 equipment end uses (SIC 2-, 3-, 4-digit)	Kilowatthour forecasts for each industry	Kilowatthour sales by end use Market share by technology Load impacts

ufacturing sector (e.g., lumber, printing, petroleum refining, transportation equipment). Forecasts can be produced for planning horizons of up to 20 years.

The econometric models are based on the principle of cost minimization; that is, industries manage their energy consumption, capital investments, and labor and material costs to minimize expenses. The models estimate changes in the manufacturing industry's electricity consumption as a function of these costs and the forecast output of each industry. After much testing,

the project team chose three forms of a cost minimization specification called KLEFM (capital, labor, electricity, fuels, materials): the static translog, the variable-cost translog, and the generalized Leontief. In addition, the nested-CES (constant elasticity of substitution) was used.

Level 1 forecasting equations use data from the U.S. Department of Commerce's Office of Business Analysis, the *Census of Manufactures*, and the *Survey of Manufactures*. EPRI provides guidelines for individual utilities to use in assembling and cali-

brating their own data to fit these equations.

The inputs for the level 1 models of INDEPTH consist of projected costs of electricity, fuels, labor, capital, and raw materials and the forecast output for each of the 20 two-digit SIC industries.

The level 2 process models forecast service-area electricity consumption for 10 key industries on the basis of the production processes used by each industry. There are two types of level 2 models: network flow models for industries in which each stage in the production process operates as a distinct unit (e.g., steelmaking), and linear programming models for industries in which the various stages of production are inter-related through the uses and flow of energy (e.g., pulp and paper, petroleum refining).

Both types of level 2 models are based on the principle that an industry selects its production processes on the basis of least cost. Within this framework, the process models simulate investment decisions made by specific industries and forecast the effect of these decisions on future industrial-sector electricity needs in the service area. The large data requirements of process models make them appropriate only for those industries that are of special interest to a utility. An industry may be important either because of its size or because of its potential for change in electricity consumption.

EPRI provides the data bases needed for 10 industry models: cement (SIC 3241), chlor-alkali (SIC 2812), steel minimills (SIC 3312), integrated steel mills (SIC 3312), glass (SIC 3220), gray iron foundries (SIC 3321), fabricated metals (SIC 3440), textiles (SIC 2281), pulp and paper (SIC 26), and petroleum refining (SIC 2911). Inputs for level 2 operation are product mix data and process details for each industry modeled.

Level 3 equipment models, now under development, estimate how the purchase, retirement, and use of various types of energy-consuming equipment (e.g., motors, chillers, dryers, space heaters, furnaces, lighting systems) affect industrial-sector electricity consumption. The models are used to examine how changes in the

ABSTRACT *In order to better meet the needs of its member utilities, EPRI has developed a package of forecasting and planning tools that account for potential changes in industrial processes and equipment. EPRI's new multilevel INDEPTH end-use planning system is a PC-based package that allows utilities to predict industrial use of electricity at the service-area level. INDEPTH can cope with the diversity of the manufacturing sector and is flexible enough to assess the effects of changes in industrial output, output mix, and electricity use per unit of output.*

market penetration of key equipment types would influence electricity consumption; to estimate the effect of rate and financial incentives, or technological advances favoring one type of equipment; and to evaluate the relative performance and cost of equipment alternatives.

Level 3 includes more than 30 types of equipment. Like the econometric and process models used in levels 1 and 2, level 3 models are based on principles of cost minimization. Unlike the other models, however, the level 3 equipment models allocate electricity consumption to various equipment types and technologies throughout the industrial sector. Level 3 models also account for changes in the equipment and technology mix and in equipment life-cycle costs that occur over the forecast period. The models use data from several industrial data bases: Drexell/INDUST, Battelle Pacific Northwest ISTUM-PC, and EPRI DSM/Industrial Response and FABMT/IMIS.

Whereas the econometric and process models emphasize forecasting, the equipment models emphasize market planning by focusing on changes in technology and the resulting effects on electricity use. In this way, the equipment models may be used to estimate the effects of incentives or techno-

logical advances favoring one equipment type over another.

Level 3 operation requires a forecast of product output, plus operating and cost characteristics for different categories of equipment.

INDEPTH provides nominal data bases for all the models it uses in order to assist utilities in providing system inputs. It will run on any IBM-compatible PC with 640K of RAM and two disk drives. Use of a hard disk and a math coprocessor is recommended.

INDEPTH applications

Several utilities have recently employed the INDEPTH system and realized significant cost savings for model development and consulting. One example is the Bonneville Power Administration. BPA's 21 pulp and paper plant customers make up 16% of its industrial load and 4.1% of its total load. BPA uses the INDEPTH model to generate long-term forecasts of electricity sales in the pulp and paper industry, and to analyze how the industry's electricity consumption could change with advances in cogeneration technology and with changing prices of electricity, oil, and gas.

Before INDEPTH, these forecasts could be generated only for the entire industry. With

INDEPTH, BPA can identify how technology and energy price changes will affect the electricity consumption of various production processes, and can identify new opportunities for marketing electricity accordingly. BPA estimates a five-year saving in avoided costs of \$451,000.

Centerior Energy Corp. (CEC) uses INDEPTH to analyze the industrial electricity sales of two of its operating companies—Toledo Edison (TE) and Cleveland Electric Illuminating Co. (CEI). With the econometric models, it has generated long-term electricity sales forecasts for each company's top six industries, based on capital, labor, materials, and energy price change scenarios. These forecasts have been used in CEC's filings to the PUC, as well as by its own marketing and rate-setting departments. CEC plans to expand this application to all 20 SIC industries represented by the econometric models. It also plans to use the process models to identify opportunities for electrification in TE's glass-making and CEI's iron and steel industries. Further, the utility intends to experiment with the equipment models to evaluate the effect of different rate designs and pricing strategies on the competitiveness of specific industrial end-use technologies.

End-Use Technology

Power Electronics

by Harshad Mehta, Electrical Systems Division

Advanced semiconductor technology capable of switching large currents at high voltage can improve the generation, delivery, and end use of bulk electric power. Increased switching speeds, enhanced reliability, and inherently lower conduction losses are among the advantages power electronics are already providing in applications ranging from ac/dc conversion on transmission lines to control of large adjustable-speed-drive motors in industry. A significant long-term research effort will be re-

quired, however, to apply power electronics in a much broader range of utility applications.

To meet this challenge, EPRI has sponsored research on power electronics for more than a decade and, in 1986, helped organize the Ad Hoc Interagency—Utility Group on Power Semiconductor Switches and Materials. This group—which includes representatives from EPRI, the U.S. Department of Energy, the National Aeronautics and Space Administration, and the U.S. De-

partment of Defense—has coordinated a broad program of national research related to power electronics. Initial emphasis has been on materials research and on development of advanced power semiconductor devices. Significant achievements have recently been made in these and related fields of research.

Materials

Power applications need purer semiconductor materials than those used in ordinary

ABSTRACT *Power electronics—sometimes called the second electronics revolution—is beginning to transform utility networks and major industrial equipment. Recent accomplishments have been achieved at the component level in the production of advanced semiconductor materials, the design of macroelectronic devices, and the development of improved device packaging. Future research will emphasize system-level issues.*

integrated circuits, because even one small material defect can cause a device failure. A primary concern of the Interagency–Utility Group is the lack of a domestic commercial source for these materials. Two EPRI projects have successfully addressed this problem by improving existing methods for producing high-purity silicon ingots. The primary goals of this materials research are to increase the diameter of silicon ingots (and the wafers cut from them), which boosts the current-carrying capacity of devices, and to increase resistivity, which raises breakdown voltage.

An advanced float-zone process developed by Westinghouse with EPRI funding has produced 95-mm-diam silicon ingots with a resistivity of 800 ohm-cm. This material is now being tested at Powerex, with results expected by the end of 1988. Although this accomplishment completes the EPRI project (RP2737-4), development work aimed at producing ingots with a resistivity of 2000 ohm-cm (compared with 500 ohm-cm for ingots available overseas) and a diameter of 125 mm (compared with the 100-mm maximum diameter now available) is continuing under Department of Defense auspices.

The less expensive Czochralski method of ingot production is being adapted by incorporating strong magnetic fields around the ingot being drawn in order to prevent inclusion of impurities. In an EPRI project

with Unisil Corp., superconducting magnets have been used for the first time in a magnetic Czochralski (MCZ) process, which has so far produced ingots with a resistivity of up to 250 ohm-cm and a diameter of 77 mm (RP2737-5).

Samples tested at Powerex and General Electric indicate that the MCZ method is feasible for producing silicon that can be used in making thyristors rated up to 4.5 kV. Samples with lower resistivity have also been sent to Texas Instruments and IBM for evaluation as raw material for making very large scale integrated (VLSI) circuits. Because the market for VLSI devices is currently much larger than that for power electronics, the commercial attractiveness of MCZ would be enhanced if the process could produce silicon ingots suitable for both markets.

The target date for completion of EPRI's project on MCZ is December 1988. Experience to date indicates that silicon produced by this method will be 25–30% less expensive than that produced by the float-zone method, which is the only process now being used commercially to produce power semiconductor materials.

Devices and packaging

The first light-triggered thyristor (LTT) was developed in 1978 with EPRI funding, and work has continued to increase the capacity of this important device. An ongoing project has developed an LTT capable of handling

8.5 kV, and researchers are confident of increasing its capacity to 10 kV once large-diameter, high-resistivity materials become available (RP2443-1).

A significant breakthrough accomplished in this project has been to increase the breakdown voltage of LTTs by reducing charge buildup around the outer edge of the processed silicon wafer. In previous devices such charge buildup created strong electric fields that led to breakdown when the applied voltage was only about 65% of the voltage for which an LTT should have been rated. By using advanced, double-positive-bevel techniques to produce smoother contours on wafer edges, breakdown voltage has now been brought more in line with theoretical device limits. Next, researchers will attempt to incorporate a built-in, self-protective feature that will turn an LTT on or off if voltage or current rises above acceptable levels.

Two new gate-turnoff (GTO) thyristors have also been successfully developed and tested. A 5-kV, 2-kA GTO suitable for use in static VAR compensators and large motor controls was developed by General Electric (RP2443-2), while Powerex developed a 4.5-kV, 1-kA GTO suitable for medium motor control and industrial applications (RP2443-3). Both devices have demonstrated conductive losses lower than those demonstrated by any commercial competitor. Although EPRI is no longer involved, the contractors are now planning to manufacture the devices, and they hope to provide prototype samples for commercial applications by the end of 1988.

Metal oxide semiconductor (MOS) technology is currently used in many low-power applications, such as watches and pocket calculators, where energy loss must be kept to a minimum. Attempts have recently been made to integrate MOS circuitry into such high-power devices as thyristors. If successful, such devices would require significantly less power to control the switching of large currents. The feasibility of MOS-controlled thyristors (MCTs) has been established, and it appears they may eventually replace GTOs in a number of utility appli-

Figure 1 In high-power applications, standard thyristor packages (foreground) must contain metallic contact plates to disperse silicon-wafer-generated heat. By replacing the large contact plates with silicon, GE can produce a lighter package (background) with improved thermal performance for a quarter of the cost.



cations because energy losses are much smaller. With achievement of this important step, EPRI's project on MCT technology has been completed (RP8001-2), and further development work will be carried on by other partners in the Interagency-Utility Group. MCTs are expected to prove especially valuable in numerous military and space applications. When MCT power capacities reach levels that are of interest to utilities, EPRI involvement is expected to resume. Eight to ten years of additional development work will probably be required before MCTs reach broad utility application.

For most high-power applications, thyristors must be packaged in modular, easily stacked units. Such packaging significantly raises the device cost, in part because the devices have large tungsten or molybdenum contact plates to disperse heat generated in the silicon wafer. Current EPRI work devoted to refining this conventional packaging technology should lower its cost by reducing the number of parts in each device and introducing more efficient production techniques (RP2443-6). This packaging, being developed by Powerex for prototype production in mid-1989, should cost 30% less and should be ready for commercial application within two years.

General Electric is pursuing a more revolutionary approach, which involves replacing metallic contact plates with silicon (RP2443-8). This research is expected to significantly reduce the size, weight, and cost of thyristors, as well as to improve their thermal performance (Figure 1). Prototype LTTs and GTOs incorporating this advanced packaging are also expected to be ready by mid-1989, but three to five years will probably be needed for the new technology to lead to commercial products. Considerable development work will still be needed to adapt manufacturing techniques to device production using the new packaging and for modifying power systems to take best advantage of them.

Future research and technology transfer

As basic materials research successfully concludes and new devices are developed that promise near-term commercialization, new research will emphasize whole systems:

- A new light source is needed for equipment applications that require relatively few series-connected LTTs. The present light source, a cesium arc lamp, is economical only for applications in which a large num-

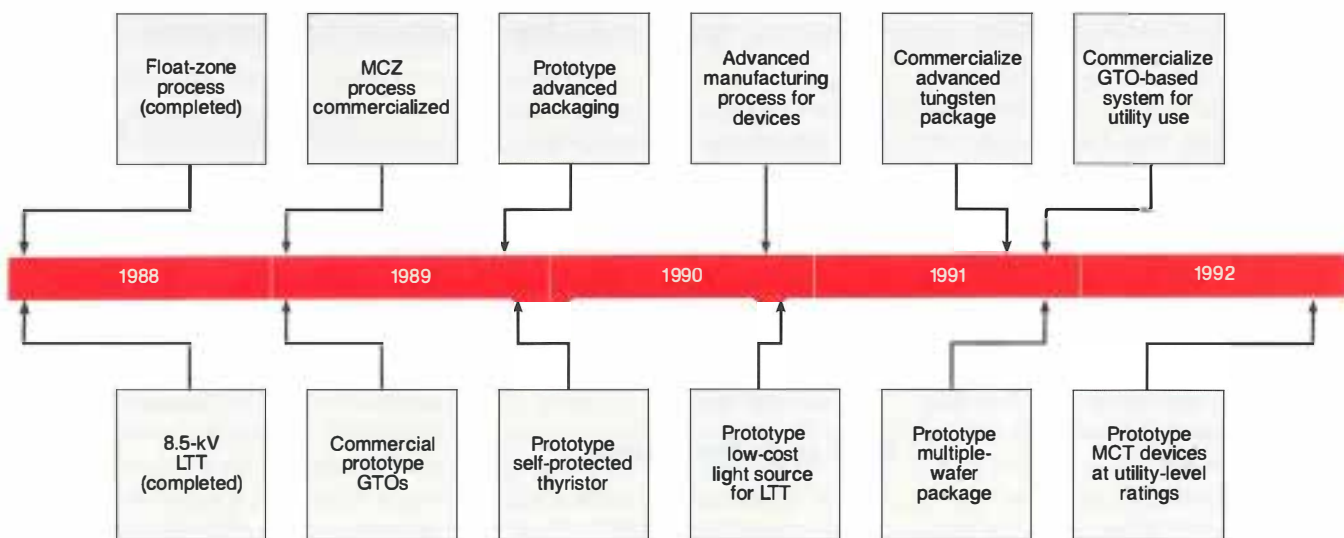


Figure 2 The listed steps show research projects (top) and the resulting device developments (bottom) as power electronics for utility applications moves toward full commercialization during the next five years. Subsequent device improvements are expected to yield significant industry savings on a modest research investment.

ber of thyristors are connected in series, as in an HVDC converter. A lower-cost light source would enable LTTs to be used in series in smaller applications, such as static VAR compensators and adjustable-speed drives.

▫ New manufacturing processes are needed to competitively produce new power electronics devices. In particular, advanced lithographic techniques will be required for etching narrower lines on silicon wafers.

▫ Multiple-wafer packages have to be developed for applications such as economical circuit switches and high-speed current interrupters. At present, only one power

thyristor wafer is enclosed in each "hockey-puck" device package.

▫ MCTs for utility applications should be explored as soon as the state of the art permits.

To help transfer power electronics technology into utility operations, EPRI will begin development of an advanced static VAR compensator incorporating the latest GTO technology. The power level of this device, expected to be ready for commercialization by 1992, will be 60 MVA. (One prototype funded by the Empire State Electric Energy Research Corp. is already operating at the 1-MVA level.)

Technology transfer is also being fos-

tered by licensing agreements with EPRI contractors and others. Westinghouse has a license to commercialize float-zone technology, and Unisil has a license for MCZ technology. License agreements for devices have been negotiated with General Electric and Powerex.

It is anticipated that 3–4 million power semiconductor devices are expected to be used by electric utilities in a variety of applications during the next 10 years. With a research investment of \$15 million to \$20 million, cumulative benefits for the utility industry from improved devices are expected to be \$300 million to \$400 million during that period (Figure 2).

Emission Control Technology

Reburning for Cyclone Boiler NO_x Control

by Angelos Kokkinos, Generation and Storage Division

Recent pilot-scale testing cosponsored by EPRI and the Gas Research Institute (GRI) indicates that reburning can reduce NO_x emissions by 40–60% in cyclone boilers when pulverized coal (PC), oil, or natural gas is used as the reburn fuel. The pilot tests, performed at the Babcock and Wilcox (B&W) Alliance Research Center using a 6 × 10⁶ Btu/h cyclone-fired pilot-scale furnace, were designed to confirm and expand upon the conclusions of an earlier B&W feasibility study. That study predicted reburning could reduce NO_x by 50% in most cyclone boilers now in operation.

Combustion modification

Cyclone boilers present a unique challenge for NO_x control. They were designed to reduce fuel preparation costs (only a coal crusher is required), furnace size, and the fly ash content of the flue gas. To do so, cyclones burn fuel at high turbulence and temperature (3000–3400°F/1649–1871°C) to remove the coal ash as molten slag. Current practice is to maintain air-rich conditions in the combustion chamber (cyclone)

to ensure that the molten slag does not corrode the cyclone boiler tubes. High turbulence and temperature under air-rich conditions, however, produce high NO_x levels in the cyclone chamber. NO_x formation can be

decreased by reducing available oxygen and combustion temperature, but this is difficult to do without encouraging corrosion or increasing fly ash and unburned carbon.

Reburning, on the other hand, destroys

ABSTRACT *Recent developments in a technology called reburning offer owners of cyclone-fired boilers a promising control method for reducing NO_x emissions. Reburning involves the injection of 10–25% of the fuel input into the furnace above the burner zone to produce substoichiometric conditions that convert NO_x to molecular nitrogen. A pilot-scale cyclone furnace test program indicated that NO_x emissions could be reduced by 40–60% using natural gas, oil, or coal as the reburn fuel. Future plans call for confirmation of these results in a full-scale utility cyclone boiler.*

Figure 1 Conceptual drawing of a cyclone boiler modified for reburning by the addition of completion air and reburning fuel ports. A fraction of the boiler's fuel is injected through reburning ports to chemically reduce NO_x formed in the main combustion zone. Supplemental air is added higher in the boiler to complete carbon combustion in the burnout zone.

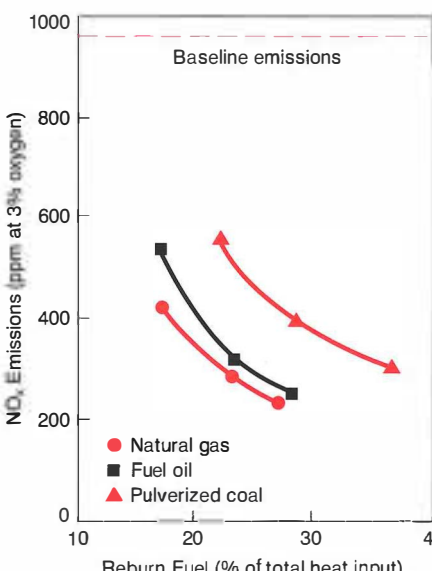
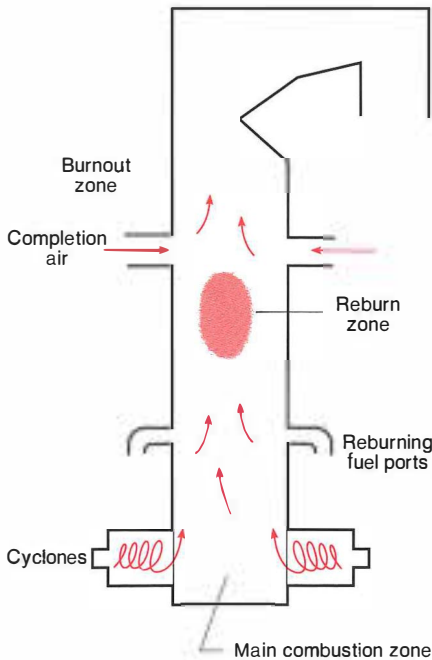


Figure 2 Tests in a pilot-scale cyclone boiler showed that reburning could reduce NO_x emissions by over 50% from the baseline level with a variety of reburn fuels. The boiler load for the tests was 6 × 10⁶ Btu/h, with a cyclone stoichiometry of 1.1 and 15% excess air.

NO_x produced in the cyclone chamber by chemically reducing it in a fuel-rich "reburn" zone. It is considered to be the most highly developed combustion modification adaptable to cyclone boilers. As shown in Figure 1, fuel representing 10–25% of the boiler's heat input is introduced through ports located above the primary combustors to create this fuel-rich reburn zone. The reburn zone destroys a certain proportion of the NO_x but leaves some carbon from the reburn fuel unburned. Combustion of this unburned carbon occurs in the burnout zone, created by injecting completion air (so called because it completes the combustion process) above the reburn zone. The amount of NO_x destroyed by reburning depends on several factors.

- Air-fuel ratio in the reburning zone. Laboratory and full-scale studies indicate that a stoichiometric ratio of 0.85–0.95 in the reburning zone optimizes NO_x reduction.
- Type of reburn fuel. More volatile, low-nitrogen-content fuels (oil, natural gas) reduce NO_x more effectively than less volatile, higher-nitrogen-content fuels (coals).
- Residence time—the length of time furnace gases remain in the reburn and burnout zones. Longer residence times allow complete mixing of furnace gases with the reburn fuel and completion air. Minimal residence times are generally 0.5 second for the reburn zone and 0.6 second for the burnout zone.
- Temperature. To maximize NO_x reduction, the temperature in the reburn zone should be as high as possible without hampering combustion in the primary zone, and the burnout zone should be as cool as possible without inhibiting carbon burnout.

Pilot tests conducted

To verify these operating parameters and provide an indication of how reburning affects corrosion and combustion efficiency, EPRI and GRI engaged B&W to conduct pilot tests. The program was designed to measure NO_x reduction rates with natural gas, oil, and coal under varying cyclone/reburn fuel ratios (fuel splits), furnace stoichiometries, and reburn and burnout air injection

locations. Corrosion and combustion efficiency were inferred from the hydrogen sulfide (H₂S) and carbon monoxide (CO) levels in the gas and from the amount of unburned carbon in the ash.

Figure 2 summarizes the NO_x reductions achieved with all three fuels as the percentage of reburn fuel was increased. About 50% NO_x reduction was achieved using pulverized coal (85% through 200 mesh) as the reburn fuel, albeit at higher reburn fuel ratios than with the other fuels. These results challenge the assumption that coal cannot provide acceptable NO_x reduction because of its low volatility and high fuel nitrogen content compared with natural gas and oil; this is encouraging, since the use of coal as a reburn fuel does not carry a significant cost penalty (primarily pulverizer energy and particulate control upgrade costs).

An additional concern with PC as a reburn fuel has been its presumed inability to achieve carbon burnout in conventional furnace residence times. However, in the pilot tests, the unburned carbon levels in the fly ash were only 3–5%, indicating that an acceptable proportion of the PC reburn fuel was completely burned. Further demonstrations on a larger scale are needed to confirm these results and demonstrate plant performance and operability at the required reburn fuel ratios.

Reburn efficiency

In further tests, the reburn fuel transport air was supplemented with recirculated flue gas to enhance mixing of the reburn fuel with the furnace gases. Flue gas recirculation (FGR) not only improves mixing but can also reduce the amount of reburn fuel required to achieve the optimal reburn stoichiometry. Hence, FGR could provide an economic benefit when a premium fuel such as natural gas is used for reburning. The results indicate, however, that FGR may be more effective with PC than with natural gas. FGR reduced NO_x by an additional 20% when used with coal but by only 10% when used with natural gas.

Reburning had minimal effects on combustion efficiency in the pilot-scale furnace,

as evidenced by low unburned carbon in the fly ash (with coal as the reburn fuel) and CO emissions equal to baseline levels. Furthermore, in tests with all three reburn fuels, the temperature of flue gas exiting the boiler increased only 50°F (10°C), a change that should not affect boiler performance significantly. Although the effect of reburning on fireside corrosion, slagging, and fouling cannot be determined conclusively

without further testing, the H₂S levels were less than 300 ppm, the approximate threshold level for significant corrosion. The effect of increased dust loading in the boiler's convective section and at the downstream particulate control system when using coal reburning was not determined and should be investigated.

A full-scale demonstration of reburning in a cyclone boiler would be the next step in

EPRI's assessment of this technology. To this end, EPRI has entered into an agreement with the Environmental Protection Agency and GRI to cosponsor a full-scale demonstration at a utility boiler. If these pilot results are confirmed at full scale, owners of cyclone-fired boilers will have a promising control method for reducing NO_x emissions at costs substantially lower than those for flue gas cleaning alternatives.

Compressed-Air Energy Storage

Status of First U.S. CAES Plant

by Robert Pollak, Generation and Storage Division

Alabama Electric Cooperative (AEC), a 45-year-old rural electric generation and transmission company serving Alabama and parts of Florida, was faced in the mid-1980s with the challenge of meeting load growth, which is expected to be 3–5% for the next 10 years. Presented with the choices for adding peaking and intermediate capacity, and aided by EPRI research on compressed-air energy storage (CAES), AEC gave serious consideration to this relatively new technology. In 1986 a thorough feasibility study concluded that CAES could be used to improve the capacity factor on AEC's 600-MW coal-fired Lowman plant, which has enough baseload capacity for the next several years, and that the most economical and technically attractive way to meet load growth was to build a 200-MW CAES plant, with phased construction of four 50-MW units between 1989 and 1993. A storage capacity of 26 hours was selected to match the shape of the AEC load curve and to use the least expensive charging energy, which is available during the weekend.

Detailed specifications were prepared for bidding this plant on a turnkey basis, and four power plant architectural/engineering firms submitted bids based on turbomachinery from one of two manufacturers: Brown Boveri Co. (now Asea Brown Boveri,

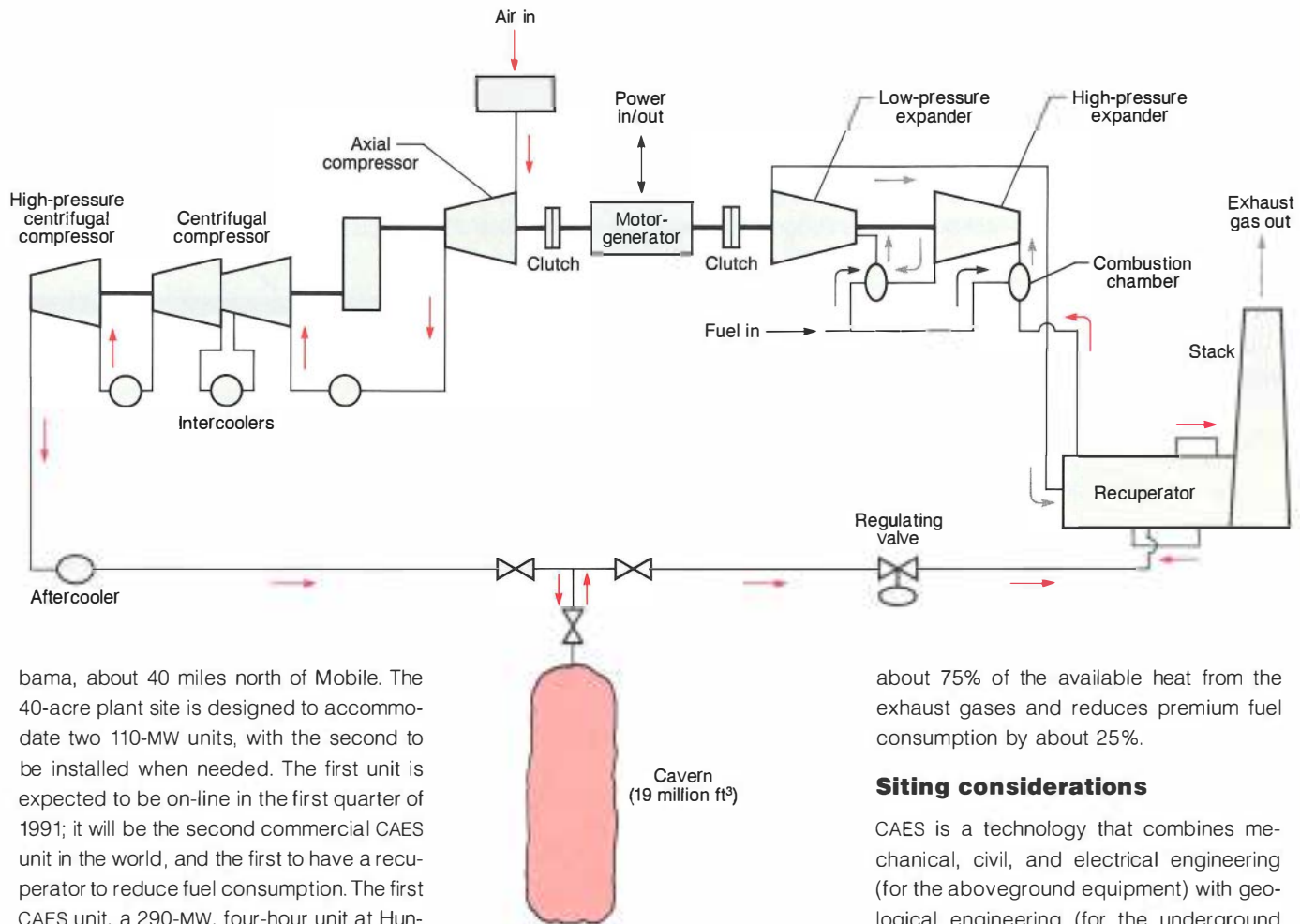
Inc.) and Dresser-Rand. The bids for the first 50-MW unit were not as economically attractive as expected. Instead, on a cost-per-kilowatt basis, a 110-MW unit turned out to be much more desirable as a result of economies of scale for the turbomachinery. Also, the additional capacity could be used by AEC sooner than originally anticipated. Specifications for the larger unit were prepared, and alternative proposals were

requested from the bidders. The 110-MW offers were reviewed in 1987, and after extensive technical and commercial evaluations, the contract was awarded early in 1988 to a joint venture of Harbert International and Gibbs & Hill (using Dresser-Rand turbomachinery and Fenix & Scisson salt cavern technology). The total contract cost will be about \$500/kW in constant 1988 dollars.

The selected site is at McIntosh, Ala-

ABSTRACT *Alabama Electric Cooperative is building, in McIntosh, Alabama, the first compressed-air energy storage plant in the United States. EPRI is providing technical assistance and funding for a first-of-a-kind recuperator for this plant. AEC chose this environmentally benign, technically conservative, and economically attractive technology to meet electricity demand in the 1990s. Completion of the 110-MW, 26-hour storage plant is scheduled for the first quarter of 1991. The total cost for the turnkey contract will be approximately \$500 /kW in constant 1988 dollars.*

Figure 1 Schematic diagram of Alabama Electric Cooperative's 110-MW, 26-hour CAES plant at McIntosh, Alabama. The plant will be the first commercial CAES unit in the world to use an exhaust heat recuperator to reduce fuel consumption.



bama, about 40 miles north of Mobile. The 40-acre plant site is designed to accommodate two 110-MW units, with the second to be installed when needed. The first unit is expected to be on-line in the first quarter of 1991; it will be the second commercial CAES unit in the world, and the first to have a recuperator to reduce fuel consumption. The first CAES unit, a 290-MW, four-hour unit at Huntorf, West Germany, went into commercial operation in 1978. It has an excellent record of availability and starting reliability (about 90% and 99%, respectively). The Soviet Union is planning to build a three-unit, 1050-MW CAES plant in the Donbass region.

What is CAES?

In a CAES plant, relatively inexpensive off-peak energy is used to drive a motor to compress air, which is stored in a suitable geologic formation (salt cavern, hard rock cavern, or an aquifer reservoir). When peaking or intermediate power is required, the stored air is brought to the surface, heated (by burning fuel), and expanded through a hot gas expander, which in turn drives a generator. Thus, a CAES plant is a hybrid

storage and generation plant. Electricity is used during the compression process, and fuel (oil or gas) is used during the generation process.

In practice, the generator and motor are combined in one synchronous machine; clutches decouple the compressors from the rest of the rotating machinery during the generation cycle and decouple the expanders during the compression cycle (Figure 1). The entire machinery train (compressors, motor-generator, and expanders) is interconnected, and the expanders can be used to bring the motor and compressors up to synchronous speed for startup. The recuperator uses turbine expander exhaust gases to preheat the cavern air; it recovers

about 75% of the available heat from the exhaust gases and reduces premium fuel consumption by about 25%.

Siting considerations

CAES is a technology that combines mechanical, civil, and electrical engineering (for the aboveground equipment) with geological engineering (for the underground cavern). The cavern technology comes from the oil and gas industry, which has over 70 years of experience in storing hydrocarbon fuels.

One of the first considerations in site selection is a location with good prospects for developing a cavern. Geologic opportunities for CAES potentially exist in about three-fourths of the United States (*EPRI Journal*, December 1983, p. 61, and June 1987, p. 41). An AEC feasibility study showed that the McIntosh salt dome, which is being used to provide raw material (sodium chloride) for a chemical plant in the area, was already well characterized. Nine caverns in the dome had already been solution-mined (solution mining, a proven method for cavern development, uses water to dissolve the salt),

and there was land available for lease above the salt dome's western boundary and adjacent to an electrical transmission line. The location of this boundary was estimated by means of surface gravity surveys. The uncertainty of the exact boundary location warranted drilling of at least one exploratory test hole between the expected salt dome boundary and the proposed first cavern site. Coring of the test hole at several depths, as well as specialized geophysical logging, would also yield valuable information concerning the quality of the salt.

The first test hole drilling was completed in July 1987, and geophysical logging was completed in August. The core samples contained magnesium and potassium salts as well as sodium chloride. These other types of salts, if present at other locations, would have made the solution mining of the cavern difficult to control. In December 1987 a second exploratory hole was drilled closer to the center of the salt dome, near the planned location of the cavern. Core samples here indicated that the salt quality is excellent, confirming the suitability of the cavern location.

Air or water quality permitting is unlikely to

be on the critical path for plant success. Once a proper geologic formation is found, siting a CAES plant is easier than siting most other types of thermal plants, since emissions from a CAES plant are relatively low. For example, in a combustion turbine plant about two-thirds of the power is used to drive the compressor, so emissions per unit of delivered power from a combustion turbine are higher, in principle, by a factor of about 3. For AEC's site and plant, there were no significant air quality problems, and the Rural Electrification Administration provided a "Finding of No Significant Impact." The entire environmental permitting process took only about three months. Because salt has been mined in the area for a long time, the mining of the cavern could be done under an existing permit. Environmental concerns regarding disposal of the brine created by the solution-mining process were avoided by using it as feedstock for the nearby chemical plant.

Operating characteristics

The turbomachinery of the CAES plant is like a combustion turbine that has been split so that the compressor and the expander

operate independently. In a combustion turbine the compressor is a slave to the expander, since they must operate at the same time and have the same air mass flow rate. In a CAES plant the compressor and the expander can be sized independently to provide the utility-selected "optimal" MW charge and discharge rating, which determines the ratio of hours of compression required for each hour of generation. The MW ratings and time ratio are influenced by the utility's load curve and by the availability, and relative cost, of off-peak power. In other words, a CAES plant can be tailored to fit a particular load curve. The Huntorf plant requires four hours of compression per hour of generation, whereas at the McIntosh plant the ratio is 1.7 hours of compression per hour of generation.

At 110-MW net output, the energy ratio is 0.818 kW input per kW output, and the heat rate (LHV) is 4122 Btu/kWh with gas fuel and 4089 Btu/kWh with fuel oil. Part-load operation of a CAES plant is very flexible: the heat rate of the expander increases less than 5%, and airflow decreases nearly linearly, when the plant is turned down to less than 45% of full load.

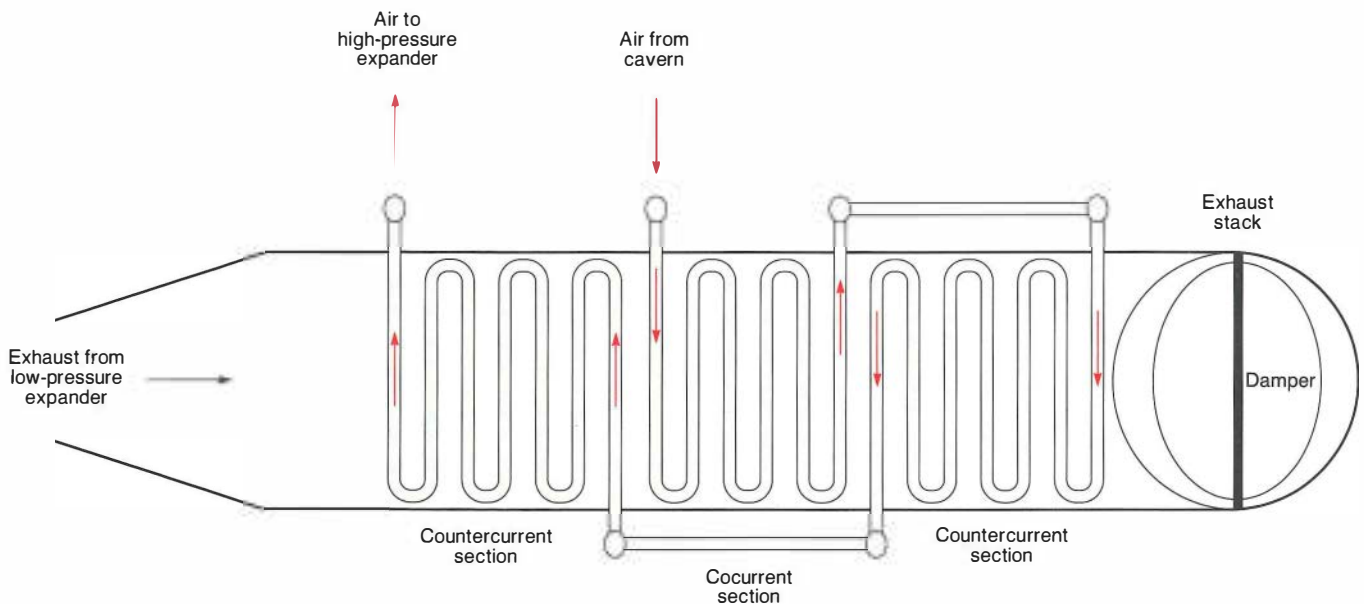


Figure 2 EPRI-developed recuperator design for AEC's CAES plant. The recuperator will use turbine expander exhaust gas to preheat cold air coming from the storage cavern. Corrosion of cold-end tubes is prevented by arranging the serpentine tubing so that the cavern air enters the midregion of the recuperator through a cocurrent section.

Turbomachinery

As shown in the diagram of the plant's turbomachinery (Figure 1), air is routed during the generation cycle from the cavern through a recuperator, where it is preheated to 550–650°F (288–343°C), depending on load. The air is then heated further (using gas or fuel oil) to 1000°F (538°C) before it enters the high-pressure expander. Exhaust air from the high-pressure expander is reheated to 1600°F (871°C) before it enters the low-pressure expander. Exhaust from the low-pressure expander enters the recuperator before being discharged to the atmosphere at 255–290°F (124–143°C).

Reheat combustion turbines are unusual in the United States. Although the entire turbomachinery train (including the compressors) for the McIntosh plant is well within the state of the art for this type of equipment, the turbine expanders and the recuperator are custom-made for this specific application. On a cost-sharing basis with the Turbodyne division of Dresser-Rand, EPRI has funded development of a low-pressure single-flow expander for use in CAES plants that would be more efficient at a higher rating than the double-flow hot gas expanders currently available (RP2488-13). This expander is the one being provided for the McIntosh plant.

Although exhaust heat recuperators have been used with combustion turbines in the past, there have been a variety of operation and maintenance problems associated with materials and construction (EPRI EM-3843). Thermal stresses, cycling fatigue, vibration,

and corrosion have been reported. One of the most serious potential problems for CAES application is corrosion due to the condensation of sulfuric acid on the outside of the cold-end tubes inside the recuperator. The acid is produced when sulfurous oxides in the exhaust (formed when fuels containing sulfur are burned) combine with water in the cold regions of the recuperator.

In 1986, through ongoing EPRI research, a recuperator design was conceived that eliminated the condensation problem by arranging the tubes and airflow so that the tube temperature would always be maintained above the dew point of sulfuric acid. The design includes a cocurrent section located between two countercurrent sections (Figure 2). The cold air from the cavern enters the recuperator cocurrent section and is warmed by hot exhaust gases at a temperature that results in an outside tube metal temperature above the sulfuric acid dew point. The rest of the heat exchanger, composed of two more sections, is piped in the conventional, countercurrent configuration to reduce tube surface area and cost. All the tubes are horizontal, finned, and arranged in a serpentine manner, with air manifold headers situated outside the hot gas path. This construction minimizes the thermal stresses at the tube-to-header joints. The plant exhaust stack will be equipped with a damper, which will be closed whenever the turbine is shut down. Closing the damper will keep the tubes warm during weekends or overnight. Although the risk associated with recuperator

failure is considered minimal, a full-size air-side bypass around the recuperator will be provided in the AEC plant. The turbine will be capable of developing 86% of full-load output with the recuperator completely bypassed, but the heat rate will increase about 22% and the airflow about 24%.

What's next?

EPRI is providing an engineer of record to document the evolutionary progress of the AEC CAES plant. This effort will begin with documentation of the historical events that led to the decision to build the plant and will produce annual progress reports; at least two years of operational data will be presented.

A principal focus of these reports will be to describe any unforeseen problems and their solution for the benefit of utilities planning to build CAES plants in the future. The results of these experiences will also be presented via oral briefings to a group of EPRI utility members closely following the CAES technology. This group, called the CAES Working Group, already has about 40 utility representatives.

Up to now the AEC plant has not encountered any major difficulties. EPRI will continue to supply the AEC project with the technical support of its in-house staff or, if a specialized problem is encountered, the expertise of outside contractors or consultants. As EPRI learns more about this plant during construction and startup, the lessons learned will be used to make the next plants easier to bid, construct, and operate.

New Contracts

<i>Project</i>	<i>Funding/ Duration</i>	<i>Contractor/EPRI Project Manager</i>	<i>Project</i>	<i>Funding/ Duration</i>	<i>Contractor/EPRI Project Manager</i>
Electrical Systems			Nuclear Power		
Soft Rot Capabilities and Interaction of Fungi and Bacteria in Fumigant-Treated Poles (RP1471-3)	\$138,200 38 months	Research Foundation, SUNY/H. Ng	Repair on Reactor Pressure Vessels and Internals (RP2059-8)	\$148,800 4 months	J. A. Jones Applied Research Co./W. Childs
Energy Management and Utilization			Nondestructive Evaluation of Low-Level Radioactive Waste Canisters for Free Water Content (RP2412-20)	\$42,500 7 months	Failure Analysis Associates/E. Bradley
Program Funding Agreement: Lithium/Metal Sulfide Battery Development (RP2415-7)	\$3,200,000 52 months	DOE/R. Swaroop	Modeling Crevice Corrosion in PWR Steam Generators (RPS407-31)	\$46,200 8 months	Dominion Engineering, Inc./L. Williams
Advanced Water Loop Heater Pump Equipment Development (RP2480-8)	\$101,500 7 months	Climate Master, Inc./ M. Blatt	Structural Basis for Thermal Treatment of Alloy 690 Steam Generator Tubing (RPS408-3)	\$45,600 11 months	Rutgers University/ C. Shoemaker
Performance of Chilled Water Coils (RP2732-24)	\$61,700 8 months	Engineering Interface Ltd./R. Wendland	Void Fraction Model Improvement for CHEC (RP2420-74)	\$50,000 7 months	S. Levy, Inc./B. Chexal
Electric Water Heater Control Parameter Determination (RP2958-6)	\$67,300 8 months	OHOP Mutual Light Co./ L. Carmichael	Real-Time Radiographic Scanner Evaluation (RP2495-9)	\$40,000 4 months	J.A. Jones Applied Research Co./N. Hirota
Environment			Implementation Guidelines for Water Chemistry Diagnostics Expert System (RP2582-15)	\$36,400 6 months	NWT Corp./B. Sun
Selenium in Aquatic Ecosystems (RP2020-11)	\$4,383,400 53 months	Tetra Tech, Inc./ D. Porcella	Influence of Irradiation and Stress/Strain on In-Reactor Behavior of High-Purity Stainless Steels (RP2680-8)	\$574,500 37 months	Siemens/L. Nelson
Cofunding for Wood Preservative Mobility Study (RP2879-3)	\$90,000 28 months	Empire State Electric Energy Research Corp./ K. Jones	Influence of Radiation-Enhanced Segregation on Irradiation-Assisted Stress Corrosion Cracking (RP2680-9)	\$99,700 19 months	Battelle, Pacific Northwest Laboratories/L. Nelson
Genetic Ecology: Biodegradation of Polyaromatic Hydrocarbons (RP3015-1)	\$601,800 41 months	University of California at Irvine/R. Goldstein	Methods for Monitoring Maintenance Performance (RP2705-11)	\$144,700 7 months	Anacapa Sciences, Inc./ H. Parris
Generation and Storage			Stress Corrosion Cracking Mechanisms in Stainless Steels (RP2812-5)	\$52,700 7 months	Johns Hopkins University/ D. Cubicciotti
Development of Li ₂ MnO ₃ as a Molten Carbonate Fuel Cell Cathode Material (RP1085-15)	\$175,000 11 months	Argonne National Laboratory/R. Goldstein	Feasibility of Detecting Initiation of Stress Corrosion Cracking (RP2812-6)	\$50,000 6 months	Rockwell International Corp./D. Cubicciotti
Baghouse-Performance-Monitoring Expert System (RP1129-22)	\$26,300 3 months	ETS, Inc./R. Chang	Evaluation of Findings of In-Service Inspection (RP2859-14)	\$30,000 7 months	MPR Associates, Inc./ J. Hosler
Manufacturing Concepts for Solid Oxide Fuel Cells (RP1676-12)	\$150,000 35 months	Texas A&M Research Foundation/R. Goldstein	Freshwater Biofilms and Corrosion of Metals (RP2939-4)	\$50,000 21 months	University of Delaware/ D. Cubicciotti
Production of Methanol by the Brookhaven National Laboratory Process (RP2146-6)	\$75,000 4 months	Stone & Webster Engineering Corp./ H. Lebowitz	Application of Computer Technology to Engineering Analysis (RP2961-1)	\$65,200 5 months	Power Computing Co./ J. Naser
Pennsylvania Highway Ash Embankment Demonstration (RP2422-19)	\$107,500 28 months	Duquesne Light Co./ D. Golden	Spent-Fuel Pool Fragility Assessment (RP2968-2)	\$30,000 4 months	Anatech Research Corp./ H. Tang
Silicon Production for High-Concentrator Solar Cells: Advanced Crystal Growth Techniques (RP2611-3)	\$175,400 11 months	Unisil/F. Goodman	Crack Arrest Toughness at High Transition Temperature (RP2975-9)	\$126,400 12 months	Battelle Memorial Institute/D. Norris
Depleted-Gas-Reservoir Field Verification Test for CAES (RP2615-11)	\$221,100 16 months	ANR Storage Co./ B. Mehta	Spatial Coherence of Strong Ground Motion for Application to Soil-Structure Interaction (RP2978-1)	\$108,900 10 months	Bechtel Group, Inc./ J. Schneider
Durability Test Plant for Advanced Model Gas Turbine (RP2774-8)	\$35,300 5 months	Encotech, Inc./C. Dohner	Experiments Related to BWR Mark I Liner Melt-Through Issue (RP3000-26)	\$120,600 7 months	Fauske and Associates, Inc./B. Sehgal
Recuperator Design Review (RP2894-3)	\$186,300 43 months	Holtec International, Inc./ R. Pollack	Dynamic and Seismic Reliability of Nuclear Piping With Wall Thinning (RP3010-1)	\$50,000 1 month	ANCO Engineers, Inc./ Y. Tang
Use of Coal Gasification in CAES Systems (RP2999-2)	\$88,900 5 months	Energy Storage and Power Consultants/ B. Louks	LMFBR Technical Integration Studies (RP3030-1)	\$90,600 11 months	Rockwell International Corp., Rocketdyne Div./ E. Rodwell
Expert System Starting Problem Investigation (RP3031-2)	\$201,700 12 months	ARINC Research Corp./ G. Quentini	Planning and Evaluation		
			Storage Technologies and Concepts: Lessons From Recently Deregulated Industries (RP1432-5)	\$79,800 7 months	Decision Focus, Inc./ S. Chapel

New Technical Reports

Requests for copies of 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, U.S. universities, or government agencies. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of EPRI reports on request. For information on how to order one-page summaries of reports, contact the EPRI Technical Information Division, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2411.

ELECTRICAL SYSTEMS

Power Line Fault Current Coupling to Nearby Natural Gas Pipelines, Vol. 3: Analysis of Pipeline Coating Impedance

EL-5472 Final Report (RP742-3); \$32.50
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Hall

Confirmation of Test Methods for Synchronous Machine Dynamic Performance Models

EL-5736 Final Report (RP2328-1); \$47.50
Contractor: Consumers Power Co.
EPRI Project Manager: J. Edmonds

RISKMIN: An Approach to Risk Evaluation in Electric Resource Planning, Vols. 1 and 2

EL-5851 (Vol. 1) Final Report (RP2537-1, -2); \$32.50
EL-5851-CCM (Vol. 2) Computer Code Manual; \$32.50
Contractor: Public Service Electric and Gas Co.
EPRI Project Manager: G. Yaacov

Turn Insulation Capability of Large AC Motors, Vols. 1 and 2

EL-5862 Final Report (RP2307-1); Vol. 1, \$40; Vol. 2, \$47.50
Contractors: Ontario Hydro Research Division; Rensselaer Polytechnic Institute
EPRI Project Manager: D. Sharma

Thermomechanical Bending Effects on Extra-High Voltage Pipe-Type Cables

EL-5880 Final Report (RP7873-1); \$40
Contractor: Power Technologies, Inc.
EPRI Project Manager: J. Shimshock

Generic Guidelines for the Life Extension of Plant Electrical Equipment

EL-5885 Final Report (RP2820-2); \$2000
Contractor: Forensic Technologies International Corp.
EPRI Project Manager: J. Stein

Evaluation of Software Development Tools, Vols. 1-3

EL-5889 Final Report (RP2715-1); Vol. 1, \$40; Vol. 2, \$40; Vol. 3, \$25
Contractor: ORI, Inc.
EPRI Project Manager: M. Lauby

Proceedings: Workshop on Power Plant Cable Condition Monitoring

EL/NP/CS-5914-SR Proceedings; \$47.50
EPRI Project Managers: J. Stein, G. Sliter, B. Dooley

Conduct and Interpretation of Load Tests on Drilled Shaft Foundations, Vol. 1: Detailed Guidelines

EL-5915 Final Report (RP1493-4); \$47.50
Contractor: Cornell University
EPRI Project Manager: V. Longo

Analysis and Design of Drilled Shaft Foundations Socketed Into Rock

EL-5918 Final Report (RP1493-4); \$32.50
Contractor: Cornell University
EPRI Project Manager: V. Longo

Morphology of Extruded Dielectric Cable Insulation

EL-5921 Final Report (RP7891); \$32.50
Contractor: University of Tennessee
EPRI Project Manager: B. Bernstein

Active Filters for High-Voltage Direct-Current (HVDC) Converter Terminals

EL-5938 Final Report (RP2115-15); \$25
Contractor: University of Minnesota
EPRI Project Manager: S. Wright

Pyrolysis and Combustion Products of Selected Utility Materials

EL-5944 Final Report (RP2028-15); \$40
Contractor: Midwest Research Institute
EPRI Project Manager: G. Addis

Pyrolysis and Combustion of Oils Contaminated With Polychlorinated Biphenyls and Tri- and Tetrachlorobenzenes

EL-5952 Interim Report (RP2028-4); \$25
Contractor: Health Research, Inc.
EPRI Project Manager: G. Addis

Proceedings: Telephone Lines Entering Power Substations

EL-5990-SR Proceedings; \$40
EPRI Project Managers: G. Addis, L. Mankoff

Transformer Overload Characteristics—Bubble Evolution

EL-5999 Interim Report (RP1289-3); \$32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: G. Addis

ENERGY MANAGEMENT AND UTILIZATION

Electrotechnology Reference Guide: Revision 1

EM-4527 (Rev. 1) Final Report (RP2613-5); \$32.50
Contractor: Resource Dynamics Corp.
EPRI Project Manager: L. Harry

Proceedings: Moving Toward Integrated Value-Based Planning—The Issues

EM-5842 Proceedings (RP2982-2); \$62.50
Contractor: Barakat, Howard & Chamberlin
EPRI Project Manager: P. Hanser

Proceedings: 1987 Annual Review of Demand-Side Planning Research

EM-5843 Proceedings (RP2381-15); \$62.50
Contractor: Barakat, Howard & Chamberlin
EPRI Project Manager: W. Smith

Retrofitting a Water-Pumping Station With Adjustable-Speed Drives: Feasibility Analysis

EM-5913 Final Report (RP2825-1); \$32.50
Contractors: CRS Serrine, Inc.; Power Electronics Applications Center
EPRI Project Manager: M. Samotyj

Small Cogeneration System Costs and Performance

EM-5954 Final Report (RP1276-27); \$500
Contractor: Science Applications International Corp.
EPRI Project Managers: H. Gransell, W. Smith, T. Oldberg

Field Performance of Residential Load Controllers

EM-5955 Final Report (RP1940-14); \$40
Contractor: BRI Systems, Inc.
EPRI Project Manager: L. Carmichael

Air Infiltration and Interzonal Airflow Measurements in Research Houses

EM-5968 Final Report (RP2034-1); \$32.50
Contractor: GEOMET Technologies, Inc.
EPRI Project Manager: J. Kesselring

Effects of Occupancy on Residential Indoor Air Quality, Infiltration, and Energy Use

EM-5994 Final Report (RP2034-1); \$25
Contractor: GEOMET Technologies, Inc.
EPRI Project Manager: J. Kesselring

ENVIRONMENT

FASTCHEM™ Package, Vol. 2: User's Guide to the EFLOW Groundwater Flow Code

EA-5870-CCM Computer Code Manual (RP2485-2); \$32.50
Contractors: Battelle, Pacific Northwest Laboratories; GeoTrans, Inc.
EPRI Project Manager: D. McIntosh

FASTCHEM™ Package, Vol. 3: User's Guide to the ETUBE Pathline and Streamtube Database Code

EA-5870-CCM Computer Code Manual (RP2485-2); \$40
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: D. McIntosh

FASTCHEM™ Package, Vol. 4: User's Guide to the ECHEM Equilibrium Geochemistry Code

EA-5870-CCM Computer Code Manual (RP2485-2); \$40
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: D. McIntosh

Multiphase Flow and Transport Models for Organic Chemicals: A Review and Assessment

EA-5976 Final Report (RP2377-5); \$32.50
Contractor: University of Michigan
EPRI Project Manager: I. Murarka

GENERATION AND STORAGE

Dissimilar-Weld Failure Analysis and Development, Vol. 6: Weld Condition and Remaining Life Assessment Manual

CS-4252 Final Report (RP1874-1); \$500
Contractor: Materials Properties Council, Inc.
EPRI Project Managers: R. Townsend, R. Viswanathan

Proceedings: Third EPRI Incipient-Failure Detection Conference

CS-5395 Proceedings (RP1863-6); \$250
Contractor: Liberty Technology Center, Inc.
EPRI Project Managers: J. Scheibel, S. Gehl

Coal Quality Information System™: User's Manual

CS-5774 Interim Report (RP1400-6, -1); \$32.50
Contractors: Kaiser Engineers, Inc.; Science Applications International Corp.
EPRI Project Managers: C. Harrison, J. Hervol

Heber Binary-Cycle Geothermal Demonstration Power Plant: Half-Load Testing, Performance, and Thermodynamics

AP-5787-SR Special Report; \$47.50
Contractor: San Diego Gas & Electric Co.
EPRI Project Manager: J. Berning

Furnace Sorbent Injection SO₂ Reduction in Cyclone-Equipped Boilers

CS-5855 Final Report (RP2533-5); \$32.50
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: G. Offen

Instrumentation Handbook for Integrated Power Plant Water Management

CS-5873 Final Report (RP2114-6); \$400
Contractor: CH2M Hill
EPRI Project Manager: W. Micheletti

EPRI Power Plant Valve Symposium

CS/NP-5878-SR Proceedings; \$500
EPRI Project Managers: S. Pace, T. McCloskey, B. Brooks

Flue Gas Desulfurization Information Resource Manager (FGDIRM) Software Reference Manual

CS-5879-CCM Computer Code Manual (RP1031-4); \$100
Contractor: Radian Corp.
EPRI Project Manager: R. Moser

User's Guide for the UNIRAM Availability Assessment Methodology: Version 2.0

AP-5897-CCM Computer Code Manual (RP1461-1); \$40
Contractor: ARINC Research Corp.
EPRI Project Manager: J. Weiss

Round-Robin Study of Methods for Trace Metal Analysis, Vols. 1 and 2

CS-5910 Final Report (RP1851-1); Vol. 1, \$85; Vol. 2, \$62.50
Contractor: TRW, Inc.
EPRI Project Manager: W. Chow

Proceedings: Effects of Coal Quality on Power Plants

CS-5936-SR Proceedings; \$300
EPRI Project Manager: A. Mehta

Proceedings: Condenser Technology Symposium

CS-5942-SR Proceedings; \$150
EPRI Project Manager: J. Tsou

An Evaluation of Integrated-Gasification-Combined-Cycle and Pulverized-Coal-Fired Steam Plants, Vols. 1 and 2

AP-5950 Final Report (RP2029-7); Vol. 1, \$47.50; Vol. 2, \$47.50
Contractor: Bechtel Group, Inc.
EPRI Project Manager: A. Lewis

Advanced Impingement-Cooled Transition Piece: Testing and Field Demonstration

AP-5964 Final Report (RP1319-10); \$25
Contractor: General Electric Co.
EPRI Project Manager: A. Cohn

Rainbow Test of Advanced Coatings for Gas Turbine Blades and Vanes

AP-5965 Interim Report (RP2465-1); \$200
Contractor: Solar Turbines Inc.
EPRI Project Manager: R. Frischmuth

Downtime Corrosion in Syngas Coolers of Entrained Slagging Gasifiers

AP-5966 Topical Report (RP2048-1); \$32.50
Contractor: Lockheed Missiles & Space Co.
EPRI Project Manager: W. Bakker

Reliability and Availability Data for Gas Turbine Generator Procurement

AP-5974 Final Report (RP2915-2); \$32.50
Contractors: Creole Production Services, Inc; Andrew Smith
EPRI Project Manager: H. Schreiber

Evaluation of Pozzolanic Applications for Leached Fly Ash

CS-5982 Final Report (RP2422-17); \$25
Contractor: Ontario Research Foundation
EPRI Project Manager: D. Golden

Field Demonstration of Wastewater Concentration by Seeded Reverse Osmosis

CS-5984 Final Report (RP2114-7); \$32.50
Contractor: Resources Conservation Co.
EPRI Project Manager: W. Micheletti

Field Testing of Behavioral Barriers for Fish Exclusion at Cooling-Water Intake Systems: Central Hudson Gas & Electric Co. Roseton Generating Station

CS-5995 Final Report (RP2214-6); \$40
Contractor: Lawler, Matusky & Skelly Engineers
EPRI Project Manager: W. Micheletti

Continuous Emission Monitoring Guidelines: Update

CS-5998 Final Report (RP1961-3); \$600
Contractor: Kilkelly Environmental Associates
EPRI Project Manager: C. Dene

Condenser Leak-Detection Guidelines Using Sulfur Hexafluoride as a Tracer Gas

CS-6014 Final Report (RP1689-20); \$150
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Tsou

GADSRAM User's Manual

AP-6016-CCM Computer Code Manual (RP2921-4); \$32.50
Contractor: ARINC Research Corp.
EPRI Project Manager: J. Weiss

Advanced SO₂ Control By-Product Utilization: Laboratory Evaluation

CS-6044 Final Report (RP2708-1); \$100
Contractor: ICF Northwest
EPRI Project Manager: D. Golden

NUCLEAR POWER

Nondestructive Evaluation Program: Progress in 1987

NP-5490-SR Special Report; \$55
Contractor: Coe Corp.
EPRI Project Manager: M. Behravesh

Experimental Determination of Turbulent Buffeting Effects in Tube Bundles

NP-5540 Final Report (RPS310-7); \$32.50
Contractor: Southwest Research Institute
EPRI Project Manager: D. Steining

Experimental Prediction of Tube Support Interaction Characteristics in Steam Generators, Vols. 1 and 2

NP-5541 Topical Report (RPS310-1); Vol. 1, \$40; Vol. 2, \$47.50
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: D. Steining

Flow Velocity and Turbulence Measurements in a Laboratory-Scale Generator Model

NP-5542 Final Report (RPS310-12); \$25
Contractor: JAYCOR
EPRI Project Manager: D. Steining

Analytic Prediction of Complex Unsteady Flow Fields in Preheat PWR Steam Generators

NP-5543 Final Report (RPS310-3); \$40
Contractor: JAYCOR
EPRI Project Manager: D. Steining

Prediction of Localized Flow Velocities and Turbulence in a PWR Steam Generator

NP-5555 Final Report (RPS310-14); \$32.50
Contractor: JAYCOR
EPRI Project Manager: D. Steining

Numerical Prediction of Turbulence-Induced Steam Generator Tube Vibration

NP-5556 Final Report (RPS310-6); \$40
Contractor: JAYCOR
EPRI Project Manager: D. Steinger

ATHOS3 Computer Code Verification, Vols. 1 and 2

NP-5557 Final Report (RPS310-8); Vol. 1, \$47.50; Vol. 2, \$32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: D. Steinger

Vibration and Wear Prediction for Steam Generator Tubes

NP-5565 Final Report (RPS310-5); \$40
Contractor: Foster Wheeler Development Corp.
EPRI Project Manager: D. Steinger

Guideline for the Utilization of Commercial-Grade Items in Nuclear Safety Related Applications (NCIG-07)

NP-5652 Final Report (RPQ101-7); \$10,000
Contractor: Gilbert/Commonwealth, Inc.
EPRI Project Manager: W. Bilanin

Valve Stem Packing Improvements

NP-5697 Final Report (RP2233-3); \$47.50
Contractor: Foster-Miller, Inc.
EPRI Project Manager: B. Brooks

ASME Code, Section XI: 1985-1987 Revisions and Updates

NP-5744 Final Report (RP2057-7); \$47.50
Contractor: Science Applications International Corp.
EPRI Project Manager: M. Behravesh

Stress Corrosion Cracking of Alloys 600 and 690 in All-Volatile-Treated Water at Elevated Temperatures

NP-5761 M Final Report (RP1450-2); \$25
NP-5761 SP Final Report; \$500
Contractor: The Babcock & Wilcox Co.
EPRI Project Manager: C. Shoemaker

Defensive Strategies for Reducing Susceptibility to Common-Cause Failures, Vols. 1 and 2

NP-5777 (Vol. 1) Final Report (RP2169-5); \$32.50
NP-5777P (Vol. 2) Forthcoming
Contractor: Saratoga Engineering Consultants
EPRI Project Manager: D. Worledge

Valve Performance in PWR Chemical and Volume Control Systems

NP-5796 Final Report (RP1935-10); \$25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: H. Ocken

BWR Cobalt Deposition Studies: Final Report

NP-5808 Final Report (RP2295-3); \$40
Contractor: GE Nuclear Energy
EPRI Project Manager: C. Wood

Modeling Babcock & Wilcox Steam Generators During Auxiliary Feedwater Injection

NP-5812 Final Report (RP2399-3); \$32.50
Contractor: Dartmouth College
EPRI Project Manager: J. Kim

Auxiliary Feedwater Spreading and Countercurrent Flow Flooding in a Model Once-Through Steam Generator

NP-5813 Final Report (RP1845-10); \$40
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Kim

Computer-Assisted Design Enhancement of a PWR Digital Control System

NP-5819 Final Report (RP2126-8); \$32.50
Contractor: Integrated Systems, Inc.
EPRI Project Manager: D. Cain

TMI-2 Technology Transfer Progress Report

NP-5821 Interim Report (RP2558-2); \$25
Contractor: Pentek, Inc.
EPRI Project Manager: R. Lambert

Proceedings: Workshop on Initiation of Stress Corrosion Cracking Under LWR Conditions

NP-5828 Proceedings (RP2812-3); \$40
Contractor: Structural Integrity Associates, Inc.
EPRI Project Managers: D. Cubicciotti, J. Nelson

Nondestructive Examination of Welds Through Painted Surfaces

NP-5834 Final Report (RP2904-1); \$25
Contractor: EG&G Idaho, Inc.
EPRI Project Manager: S. Liu

FATIGUEPRO: On-Line Fatigue Usage Transient Monitoring System

NP-5835M Final Report (RP2688-3); \$25
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: T. Griesbach

Assessing the Costs, Risks, and Benefits of Snubber Reduction: A Comprehensive Framework

NP-5854 Interim Report (RP2689-3); \$25
Contractor: Pickard, Lowe and Garrick, Inc.
EPRI Project Manager: S. Tagart

Influence of Forward-Pumped Heater Drains and Magnetic Filtration on Water Chemistry and Radiation Buildup in BWRs

NP-5864 Final Report (RP1445-6); \$32.50
Contractor: ABB Atom
EPRI Project Manager: C. Wood

Feature-Enhanced-Imaging Field Trials: Peach Bottom Unit 3

NP-5865 Interim Report (RP1570-2); \$32.50
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: G. Dau

PLANNING AND EVALUATION

EPRI Fuel Forecast Review: Report Binder and Current Research Results

P-5711 Report Binder (RP2369-20)
Contractor: Putnam, Hayes & Bartless, Inc.
EPRI Project Manager: H. Mueller

Proceedings: 1987 Fuel Supply Seminar

P-5993 Proceedings (RP2369-10); \$47.50
Contractor: Atlantis, Inc.
EPRI Project Manager: J. Platt

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

DECEMBER

13-15

Power System Operations: Research Needs and Priorities
Dallas, Texas

Contact: David Curtice, (415) 855-2832

JANUARY

24-26

The Future of Coal Handling Systems
Pensacola, Florida

Contact: Clark Harrison, (412) 479-3503

FEBRUARY

7-9

Fossil Plant Control and Automation
Miami, Florida

Contact: Murthy Divakaruni, (415) 855-2409

MARCH

7-9

Symposium: Energy Utilization
San Francisco, California

Contact: David Rigney, (415) 855-2419

7-9

Solid-Particle Erosion in Steam Turbines
New Orleans, Louisiana

Contact: Tom McCloskey, (415) 855-2655

APRIL

18-20

Workshop: Coal Weighing and Sampling
St. Louis, Missouri

Contact: Clark Harrison, (412) 479-3503

MAY

2-4

4th National Conference on Demand-Side Management
Cincinnati, Ohio

Contact: Steven Braithwait, (415) 855-2606

JUNE

5-8

Expert Systems Applications for the Electric Power Industry
Orlando, Florida

Contact: Joseph Naser, (415) 855-2107

Authors and Articles



Blatt



Hansen



Mueller



Perhac



Allan

The Rise of International Suppliers (page 4) surveys the recent, rapid, and continuing internationalization of major utility industry suppliers. The author, Taylor Moore, senior feature writer of the *Journal*, drew on presentations by utility, manufacturer, and government officials to a panel of EPRI advisers, as well as on the thinking of those advisers

and of several EPRI management executives. ■

Putting the Freeze on Refrigeration Costs (page 16) was written by Jon Cohen, science writer, aided by Morton Blatt of EPRI's Energy Management and Utilization (Customer Systems) Division.

Blatt, a project manager for research on energy systems for commercial buildings, came to EPRI in 1985 after seven years with Science Applications International Corp. in the development of energy-efficient HVAC equipment. Still earlier, Blatt worked for 12 years with General Dynamics in cryogenic systems and heat transfer analysis. He graduated in mechanical engineering from Cooper Union, earned an MS in industrial engineering at New York University, and has a master's degree in business administration from San Diego State. ■

John Gibbons: Pursuing the Conservator Society (page 22) traces the evolving career interests and thinking of a former physics researcher who has headed the Congressional Office of Technology Assessment for the last nine years. Also a member of EPRI's Advisory Council, Gibbons was interviewed by *Journal* feature editor Ralph Whitaker. ■

Reality Test for Acid Rain Models (page 28) was written by David Boutacoff, *Journal* feature writer, aided by four research managers of EPRI's Environmental Science Department.

Alan Hansen is a project manager and specialist in air chemistry with the Air Quality Studies Program. He has been at EPRI since 1985, after eight years as manager of an environmental chemistry group for Environmental Research & Technology, Inc. He was previously an environmental analyst

and a research chemist with the EPA, the University of California (Riverside) Air Pollution Research Center, and SRI International. Hansen has a BA in chemistry from Southern Illinois University and a PhD from the University of California (Irvine).

Peter Mueller, who has headed the Air Quality Studies Program since April 1987, came to EPRI in 1980, following seven years with Environmental Research & Technology, where he was manager of an environmental chemistry center. Before that, he had served briefly at the EPA and had worked for 16 years with the California Department of Health, becoming director of its air and industrial hygiene laboratory. Mueller earned a BS in chemistry from George Washington University and an MS and a PhD in environmental science from Rutgers.

Ralph Perhac, director of the Environmental Science Department since 1980, joined EPRI in 1976 as a program manager. For the two preceding years he directed a National Science Foundation program on the environmental effects of energy, and from 1967 to 1974 he was a professor of geochemistry at the University of Tennessee. Still earlier, Perhac was a field geologist for 15 years, working with mining and oil companies and the Atomic Energy Commission. He has BA and MA degrees in geology from Columbia and Cornell, respectively, and a PhD in geochemistry from the University of Michigan.

Mary Ann Allan, a project manager in the Air Quality Studies Program, has been particularly involved with data analysis for the Utility Acid Precipitation Study. She came to EPRI in 1980 after three years as a physical science technician for the U.S. Geological Survey. Allan has a BS in renewable natural resources from the University of California (Davis). ■

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