The Next 20 Years

ELECTRIC POWER RESEARCH INSTITUTE

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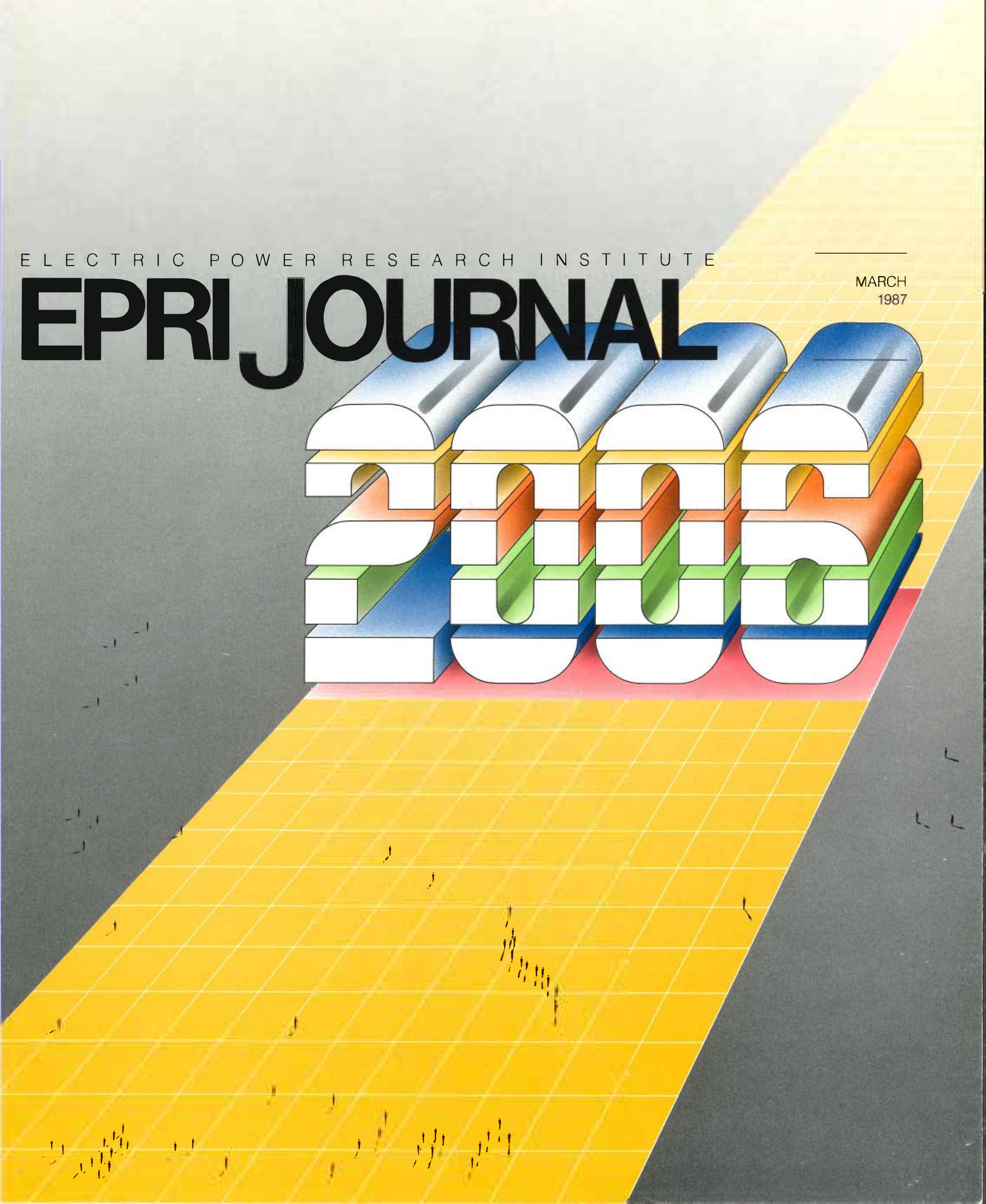

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Preparing for Life in 2006

Young

My wife and I often wonder what we will be doing in 20 years. Some things seem clear: I will have retired from EPRI, our children will all be married and on their own, and some of *their* children may even be starting families. But by the year 2006, changes in the economy, government services, business practice, and science will have affected our lifestyle in ways that are harder to predict. What will our retirement investments be worth? Will medical advances have increased our life expectancy significantly beyond the three score and ten now assumed? If we are still alive in 2006, will we be living in a condo on the beach or in the intensive care unit of some hospital?

These questions are important to us because where we will be in 20 years depends in large part on what we do now. I have similar interests in the future of the electric utility industry—not just because this is my chosen field of work but because electricity is intimately tied in with progress in our society and the quality of life we have come to enjoy. Part of EPRI's responsibility is to design an R&D program that will anticipate change and produce results equal to what the world will demand 20 or 30 years from now.

Strategic planning at EPRI draws on many sources to provide such a framework. Among the most important of these is the Advisory Council, a group of distinguished citizens from almost every walk of life. Last year the Council's Summer Seminar focused on the following question: What will life be like in the year 2006 and what will it mean for the country and the industry? The seminar discussions, reviewed in this issue of the *Journal*, were both wide-ranging and sobering. The Council saw increasing social and economic pressures building in the United States as we move toward a more global economic system. It saw turbulence likely to affect each of us as change crops up at all levels of society—redistribution of power and wealth, shifts in social attitudes, and subtle realignment of the roles of government, business, and the individual.

The Advisory Council also saw changes ahead for the electric utility industry itself and discussed emphases and priorities necessary to address the increased competition of global economics. New uses of electricity should be sought that will offer higher productivity for industry, greater efficiency for business, and a better quality of life for the individual. The development of flexible generation and transmission options will be key to helping utilities themselves stay competitive. And greater emphasis on exploratory research will be needed to accelerate progress in all areas of interest.

The challenges will be tough but rewarding. As the Council pointed out, research on electric utility technologies will be absolutely essential to carry us forward to a successful future. Personally, I'm excited about Life in 2006—that condo on the beach sounds better all the time.

Frank S. Young

Frank S. Young
Manager, Strategic Planning
Planning and Evaluation Division

Authors and Articles

Barker   Maulbetsch   McElroy   Eskinazi   Fickett

The **World of 2006** (page 4) summarizes insights, forecasts, guesstimates, and predictions for the state of U.S. society and business 20 years in the future. Five presentations at the 1986 seminar of EPRI's Advisory Council were the major resource tapped by **Brent Barker,** the *Journal*'s editor in chief.

Barker has headed the *Journal* staff since he came to EPRI in 1977. Formerly a writer and communications consultant, he was an industrial economist at SRI International from 1968 to 1973 and, before that, a commercial research analyst at USX Corp. Barker graduated from Johns Hopkins University in engineering science and earned an MBA at the University of Pittsburgh. ■

Retrofit Strategies for NO_x Control (page 26) describes utility demonstration projects that are expected to prove the practicality of boiler modifications for reducing NO_x emissions from fossil fuel power plants. Written by John Douglas, science writer, aided by three research managers of EPRI's Coal Combustion Systems Division.

John Maulbetsch has managed the Air Quality Control Program since October 1984, following eight years in charge of heat, waste, and water management research. At EPRI since 1975, he was previously with Dynatech Corp. for seven years, directing research on energy topics. Maulbetsch has three degrees in mechanical engineering from the Massachusetts Institute of Technology, where he taught for three years.

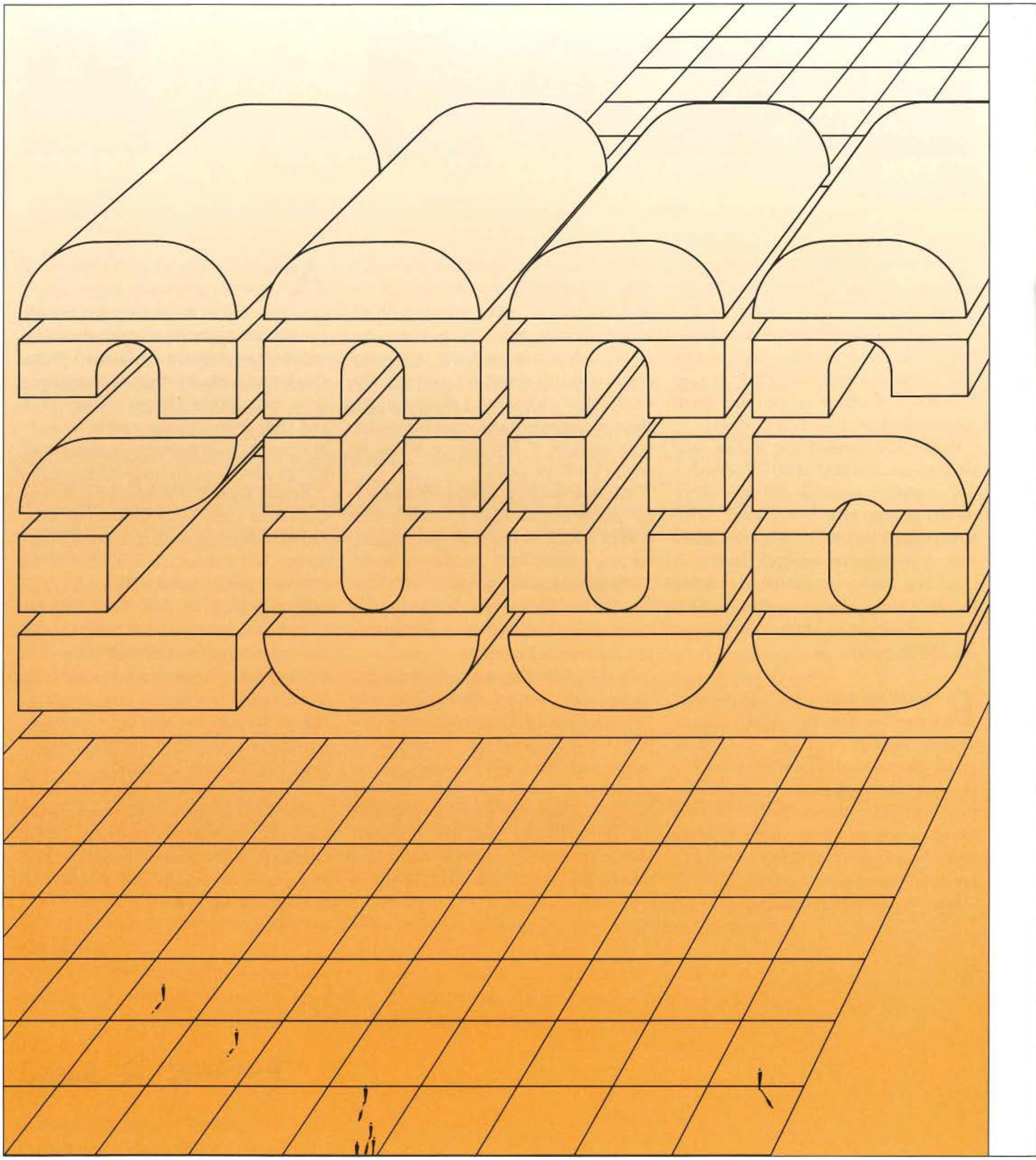
Michael McElroy, a project manager in air quality control since he started with EPRI in 1976, now heads the subprogram for NO_x control R&D. McElroy was formerly a field research engineer with KVB, Inc. He has BS and MS degrees in mechanical engineering from the University of California at Berkeley.

David Eskinazi manages research, primarily in NO_x control. He has been with EPRI since 1982, having come from Dynatech Corp., where his research dealt largely with the fluid mechanics of combustion and exhaust systems. Eskinazi has a BS in aerospace engineering from the University of Southern California and an MS in environmental engineering science from the California Institute of Technology. ■

Appliance Efficiency on the Fast Track (page 32) pinpoints major design innovations that are cutting the energy needed for many residential electricity applications. Written by Michael Shepard, *Journal* feature writer, with contributions from EPRI's Energy Management and Utilization Division and several organizations with expertise in patterns of energy use.

Arnold Fickett, director of the Energy Utilization Dept. since October of 1985, formerly directed research in energy conversion and storage. He came to EPRI in 1974 as a program manager for fuel cell R&D, following 18 years with General Electric Co., mostly in the research and development of fuel cells and other electrochemical components but eventually as manager of an engineering program. Fickett has a BS in chemistry from Bates College and an MS in electrochemistry from Northeastern University.

Others who assisted Shepard were Howard Geller of the American Council for an Energy-Efficient Economy, David Goldstein of the Natural Resources Defense Council, and Robert Johnson of Whirlpool Corp. ■



The World of 2006

by Brent Barker

In today's fast-changing and increasingly competitive world, you need to be able to predict the future just to keep up with the present. The trends, forces, and issues expected to emerge over the next 20 years were probed in the latest EPRI Advisory Council seminar as participants wrestled with the question, "What will life be like in the year 2006?"

Two centuries ago, just about the time American settlers were first cresting the Alleghenies, and just about the time steam was first being harnessed into practical machines in the coal fields of England, Thomas Malthus predicted the doom of humanity. Geometric population growth would soon outstrip the agricultural resources of the world, he reasoned and proved mathematically. Drawing on the reality of the eighteenth century, Malthus, a prominent economist, failed to see the industrial revolution lying just around the corner. He could not imagine the explosive burst of productivity when the descendants of those early settlers and those early machines were to come together on the farms of North America. And he failed to understand, as many do today, that our resource base can be fundamentally expanded, rather than depleted, through the use of new technology.

Global population at the time of Malthus's prediction was about 900 million people. Today we stand at just under 5 billion and foresee no fundamental problem in sustaining the 6 billion people expected to be living on the earth at the turn of the century. Beyond this is anybody's guess. For we stand today in the same general relationship to the biologic revolution of the twenty-first century as Malthus did to the Industrial Revolution of the nineteenth century. We, like Malthus, can't quite see around the next big corner.

We know we are already turning one major corner in which technical advances—from transporation to telecommunications to computers to weapons—are thrusting the political and economic islands of the world together at an unprecedented rate, fusing the destinies of nations, and allowing populations to soar, industry to migrate, and cultures to collide. Underdeveloped nations are bent on transforming themselves into modern economic states in decades rather than centuries, adopting western values wholesale, and, in some cases, fueling fires of fundamentalist backlash.

Change is being felt everywhere at home, and the electric power industry, like the U.S. economy itself, stands on the threshold of major change—change not quite of its own making or within its own control; change not entirely predictable. It was in this context that the EPRI Advisory Council met to consider and explore life in 2006, hoping less to predict the future than to uncover the major forces influencing it and to use this assessment to help shape the long-range planning of an electric utility research program. Five speakers were invited to discuss topics of importance in painting a picture of the world in 20 years, and on the following pages are intrepretive summaries of the key presentations.

As the three-day meeting progressed, the scope broadened from a national to a more global outlook. Discussion moved from questions of national identity and values through predictions of political and economic change to consideration of the role of science and technology in the coming century. Although discussion among the 60 participants was wide-ranging, the picture began to build as common threads and conclusions from one presentation reinforced or set the stage for others.

One conclusion that would be strongly felt as the meeting unfolded was that coming decades would be considerably more complicated than the present, in large measure through the quickening interactiveness of the global economy and through new concerns for the global environment. But the opening presentation centered on the most basic of questions: demographically, who as Americans are we now, and who will we be in the future.

THE WORLD OF 2006

Demographics and Lifestyle

Peter Morrison, director of the Population Research Center at Rand Corp., led off the seminar with an overview of demographic change in the United States. "Major demographic shifts," he noted, "typically unfold gradually, but their implications and impacts are long-lasting, restructuring markets and reshaping political agendas." He cited three trends of particular importance in understanding the world of 2006: the growing diversification of American families, the movement of women into the workforce, and the post–World War II baby boom.

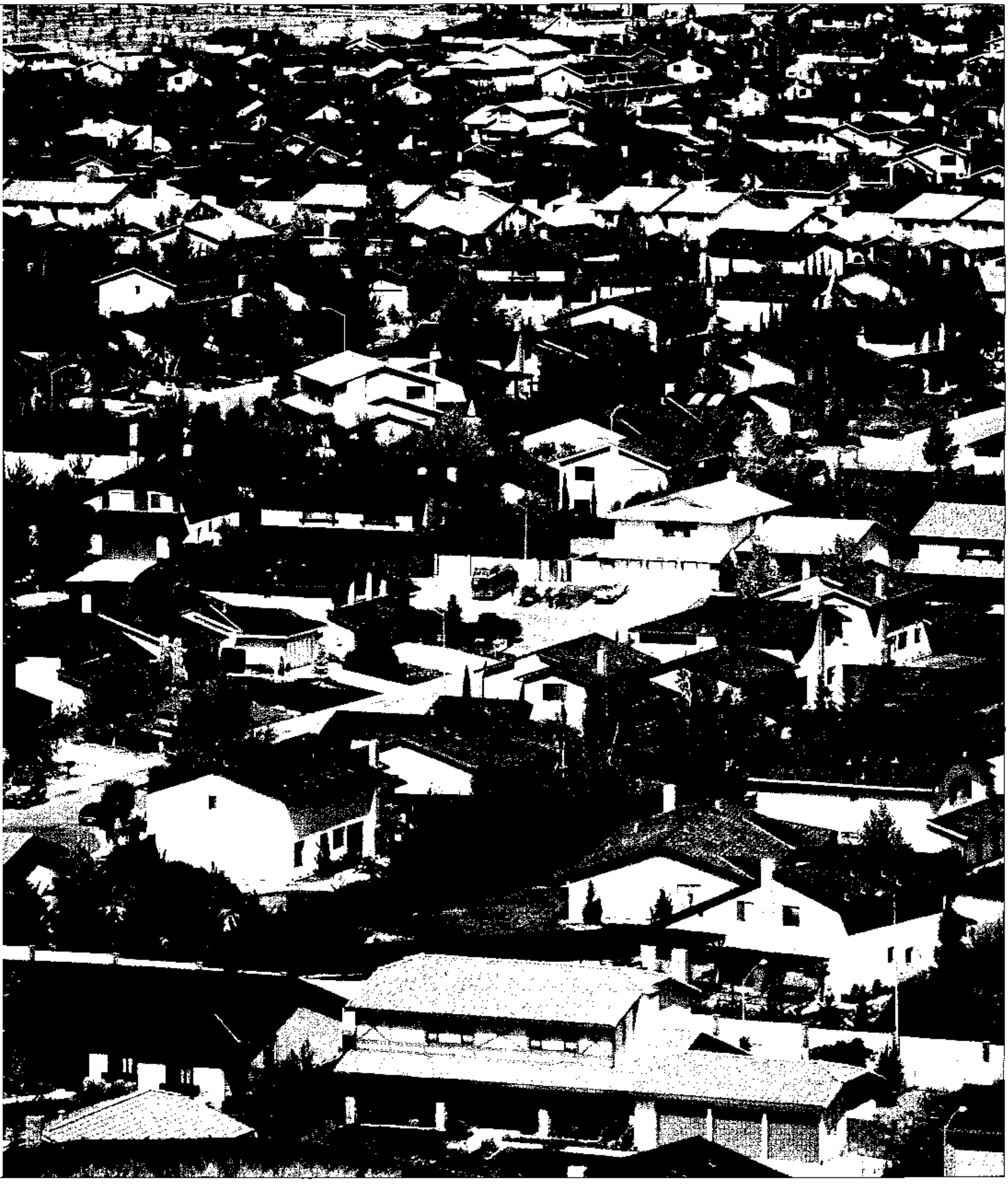
The grand stereotype of the traditional American family household composed of a married couple with two or three children appears to be very much on the wane. Households are not only getting smaller but more diverse in their living arrangements. Unusual types are becoming more common: childless couples, blended families, single-parent households, and a diverse array of people living alone—the young, the divorced, the unmarried, the elderly. In fact, the only group to register a decline over the last 15 years has been the traditional family; the number of households with a married couple and children has dropped from 40% of all households in 1970 to 28% in 1985. And Morrison projects that "through 1995, half of the increase in new households will be in the so-called nonfamily categories."

The American household is likely to average only 2.3 people in the 1990s, down from 2.7 today, down from 3.1 in 1970, and down from 4.5 just prior to WW II. Part of this decline stems from growing economic independence coupled with a desire for privacy on the part of individuals that leads them to spin off households of their own. And some of it is due to the tendency of people to divorce progressively earlier in their adult lives. But overall, much of it can be attributed simply to a decline in fertility rates. The United States dropped below the replacement rate of 2.1 children per couple in the early 1970s and has leveled off over the last decade at 1.8 children per couple. If the rate in some Western European countries (as low as 1.3) is indicative, the U.S. rate could inch down even further.

An axiom in demographics, according to Morrison, is that fertility delayed is in some measure fertility foregone, leading to fewer children. Because of the tendency to delay having children, he projects that 25–28% of all women now in their late twenties will remain childless, compared with say 10% of women now in their mid-forties. Morrison notes that this could well change, but "the long-term implication of this country remaining below replacement level is that immigration will be needed to replenish the population, making the society more multiethnic."

The movement of women into the workforce presages one of the largest economic turns of the twentieth century. Fifty years ago, only about one in four women worked for pay outside the home; today it is one in two, and by 2006 it may well be three in four. The movement of the married fraction of women has been even more rapid, and the rate of entry for women with preschool children has been sharper still. In 1950 only about 12% of mothers with preschoolers worked outside the home; today, 52%.

The economic impact is more dollars flowing into family budgets and a struggle by families to fill in behind the working woman with purchased services for cleaning, childcare, feeding family members who are in different places at mealtime, and the like. Economically, the homemaker role is being fragmented into different functions that gradually are being contracted out, providing a broad new stimulus to the generation of jobs in the service sector. Realistically though, the inability or unwillingness of most families to buy all the former homemaker services has created intense time pressures. "The upshot," says Morrison, "is a new generation of time-sensitive consumers for whom the scarcest resource is not money but time. Households will reconfigure the division of labor, service needs will broaden as families trade dollars for time, and buying habits will



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Peter Morrison

become more convenience-oriented. We can expect more one-stop shopping, direct mail and catalog purchasing. And home-centered meals will further erode as people take on what has been facetiously described as grazing throughout the day."

Each generation of women in this century has entered the workforce in a greater proportion than the last and at an earlier age. Starting at the early part of the twenty-first century, Morrison says, "We are looking into a world in which the vast majority of women work for pay and where there is substantial convergence in the careers and wages of women and men."

The entry of women is one of two streams converging to swell the American labor market in the last 15 years. The other is the baby boom generation, whose maturation over time has been likened to the passage of a pig in a python. The economy has had difficulty digesting its mass, with the result that some of its members were unemployed, others were forced into underemployment, entry wages fell as a percent of peak-earner wages from 59% to 50%, and American productivity began to slump. The constriction left some lasting scars. As Morrison sees it, "The world view of some of these young people was permanently altered."

Morrison sees the baby boom as "one of the most pervasive and far-reaching demographics of our time because of the alternate expansion and contraction it produces in different age groups." Projecting to 2006, boomers will range in age from 42 to 60; typically those are years of high productivity, peak earnings, and asset accumulation. Presumably, this will yield large positive economic benefits. Entrepreneurial activity may also increase as boomers face congested career ladders, which may induce many to switch careers in mid life.

Following in the wake of the baby boom is the so-called baby bust, bringing its own form of economic imbalance. This is already being felt in the developing shortage of entry level workers for service jobs. Wages will gradually be bid up, and by 1995 Morrison expects entry wages as a percent of peak earnings to rise to their 1967 level of 59%. The surge in pay requirements and difficulties in recruiting new workers will provide an impetus favoring automation or other means to reduce the reliance on labor.

One continuing source of new labor is immigration. The net influx to the United States typically runs 800,000 to 1 million per year, roughly one-half legal and one-half illegal, plus episodic bursts of a few hundred thousand from refugee waves. Over the years the origins have shifted to predominantly Asia and Latin America, and the influx has been highly concentrated in five states: California, New York, Texas, Illinois, and Florida. California alone absorbs 25% of the total. Most of the participants felt that over the next two decades the pressures for entry, particularly from Latin America, would build enormously. These pressures will be fed by the soaring population of jobless young, by the potential political instabilities of the region, and by the access and allure afforded by modern transportation and communication.

Even with renewed immigration, the aggregate effect of these demographic changes will be an aging American population. The percentage of the population over age 65 will approach that of modern-day Florida (17%) by the early part of the twenty-first century and continue rising thereafter. It will reach 20% in 2025 and peak at around 22% in 2050. "But the real change," predicts Morrison, "will be the sharp increase in the very old. More and more people will live into their eighties, and the state of their health will have formidable economic and social implications. In fact, the health care needs of the baby boom will be a looming political issue by 2006. I've seen some optimistic predictions about Social Security, but I think we have given ourselves a false sense of optimism about this. The financial imbalance could hit us like a ton of bricks around 2012, and I think the political reality will materialize earlier—by the turn of the century."

Morrisons' demographic projections afforded a ground-floor, statistical glimpse of who we are and what we will become. But our real identity is equally tied up in our interactions and perceptions in the elusive world of culture, values, and beliefs. The attitudes we will be carrying with us as a society into the twenty-first century were the next focus of the seminar. ■

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Values and Beliefs

Ann Clurman, senior vice president of Yankelovich, Skelly and White, turned the attention of the seminar to American values and beliefs, tracing their evolution from WW II to today and projecting a set of values seen to be newly emerging in the 1980s. Her information is based on the proprietary YSW *Monitor,* an annual survey taken in the homes of 2500 Americans over age 16.

Clurman's conclusion regarding social change is that "the past is not necessarily prologue to the future. Social change is a dialectic process—not a pendulum and not linear but rather a distillation of past elements into something new. The materialism and vein of traditionalism we are now seeing in our culture is not a return to the 1950s. We are now blending values from two distinct postwar periods, but with a new wrinkle: Ours is no longer an assumptive culture."

By this Clurman means we have been in an assumptive posture since WW II—assuming stability, assuming economic prosperity, assuming that if we play by the rules of the game we will be justly rewarded. Assumptiveness, its changing nature and eventual erosion, is one of the themes necessary to understand shifting American values. Another underlying theme is morality. "Americans are a very moral people and have always had a strong moral focus. Only the character of the focus has changed over time."

Weaving these thematic threads, Clurman described the two basic postwar shifts in American values—one in the late 1950s and early 1960s, another in the late 1970s and early 1980s.

"To understand the first shift you have to go back to the immediate postwar environment. In the late 1940s and 1950s, the country took on an ambitious economic agenda as factories that were geared for war converted to domestic production. The shared value of the time was upward mobility, expressed through material possessions. We were a conformist society, highly oriented to authority, priding ourselves on a sense of order. And our moral focus was deeply personal, characterized by the admonition, 'Live your life the right way!'"

But she observed that by the late 1950s the psychology of affluence had taken a new turn. "Americans had come to believe that the struggle for survival was essentially over in the United States, and this had very significant results. Parents eased up on their children (the baby boomers) in terms of conditioning them for hard times; the economic agenda was taken for granted and put on a back burner; and youth began a search for a new kind of personal freedom. By the early 1960s, the country's values were beginning to shift from an economic agenda to a social agenda and from a private moral focus to a public moral focus."

The new public morality was expressed by a desire to spread middle-class lifestyle to everyone and to see business and government clean and aboveboard. The firm focus on the morality of large institutions and public issues allowed the bonds of personal conformity to loosen, and individualism flourished.

"Everyone decided he or she was unique," reflected Clurman, "and marketers fed the conviction with a diversity of products. Notions of families broadened, affiliations became fluid, and people became interested in the breadth of experience rather than stability. Throughout the 1960s and into the 1970s, these social values were assimilated progressively, passing from the young upscale to the young downscale to the older upscale to the older downscale. Even Archie Bunker wasn't immune from the acculturation; he certainly wasn't the same guy when he went off the air after 10 or 12 years."

During the 1970s self-discovery reigned while "morally, public values and public institutions went out of sync. Government and business were cast as villains. Even the economic downturns of the early 1970s failed to derail these beliefs."

But by 1979 the second major shift in postwar values had begun, a shift that in some ways is still unfolding today. It was brought about in part by a new and seemingly intractable economic agenda arising out of the reality of global economic competition. It was also arising out of disillusionment with the tenets of the social agenda and the preoccupation with self.

> **“** Americans are clearly feeling the need to go beyond the pragmatism of the early 1980s, beyond simply working one's options, and beyond the brutal, materialistic instincts of the killer yuppies. People are coming up empty; they are searching for some means to nurture their souls. **”**
>
> *Ann Clurman*

By the early 1980s the postwar assumptive posture had eroded and following a burst of anxiety and confusion, in its place emerged something Clurman calls the "New Realism," a tempered approach in which people understand they cannot have it all, be it all, try it all. She maintains that although we no longer take our economic prosperity for granted as we did in the 1960s and 1970s, this does not signal a return to the immediate postwar values."Our culture is in some ways now trying to blend the economic agenda of the 1940s and 1950s with the social agenda of the 1960s and 1970s.

"This is a very pivotal time," explains Clurman, "because the moral focus is still emerging. It appears to be not as private as the 1950s or as public as the 1970s, but Americans are clearly feeling the need to go beyond the pragmatism of the early 1980s, beyond simply working one's options, and beyond the brutal, materialistic instincts of the killer yuppies. Similarly, people are finding that fitness and finance, the twin loves of the baby boomers in the 1970s, are just not enough. People are coming up empty; they are searching for some means to nuture their souls." She added that this appears not to be an isolated phenomenon, that the need for something approaching a spiritual dimension is also showing up in the data from Europe, as is a desire for control over the future, which is linked to Europe's being a possible battleground for the superpowers.

Looking ahead, Clurman suggests watching the so-called new-collar workers. Neither white collar nor blue, they are 25 million strong, mainstream, earning between $30,000 and $40,000, and employed as teachers, cab drivers, small contractors, managers of McDonald's, and so on. She considers them important because she foresees their values spreading to the rest of the American population in the next two decades. "They dislike bureaucracy, greed, elitism, and they tend to be patriotic, committed to a sense of family and liberal on women's rights, abortion, and school prayer. They put a high premium on self-reliance and are concerned about a sense of control."

The trend toward control and self-reliance will be very strong over the next 15–20 years, according to Clurman. This will translate into desires for stability and contentment and less regard for rapidly changing fashions and fads; for astute consumerism and a new sense of consumer power; for open and honest exchange of information in order to determine one's own trade-offs. The new consumers, in Clurman's view, will be educated and sophisticated shoppers, demanding value and service, and expecting a more open and honest social contract between consumer and manufacturer. "The revival of consumer power will not be a return to Naderism. It will be market directed: 'Detroit, design the car I want!' "

Clurman also anticipates a renewed emphasis on family as part of a larger trend toward allegiances to communities and regions and the revival of the home as a center of emotional satisfaction. But one very large unknown is what the Americans coming of age in the year 2006 will be like. "We have an unprecedented group of children being raised without the nurturing mother at home," says Clurman. "The jury is still out on this one. One camp says they will develop an earlier sense of self-reliance from their peers. The other camp is dubious about when and how they will develop a sense of discipline and superego."

A more certain social problem is the development of an entrenched two-tier society within the United States. On the one hand, we are developing a group of what Clurman calls gourmet babies with the best of everything and every intellectual advantage. On the other hand, one out of five babies is born out of wedlock in the United States, many without any real chance to develop intellectually."We may be developing a permanent class of underemployed people and seeding conflict between haves and have-nots. Since we as a culture do not tolerate losers in large numbers, over the next 20 years we will be developing a new sense of working egalitarianism."

The projection and clash of values and beliefs have had profound effects on postwar American politics, and the emerging concerns for self-reliance and control are likely to change the nature of participatory government. The seminar next turned to explore politics and regulation. ■

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Politics and Regulation

"The most profound political change in the last 40 years has been the weakening of our political parties," said William Ruckelshaus, now Of Counsel with the Perkins Coie law firm in Seattle. "The result is that Congress lacks discipline and looks increasingly anachronistic. It finds it ever more difficult to grapple with complex issues, and thus special interest groups continue to play an important role in shaping our laws and our political future."

Ruckelshaus is not optimistic about seeing this trend reversed in the near term, but for the longer term he shares René Dubos's view that trend is not destiny. This reflects his preference to step beyond prediction in order to separate out those issues and events that are not inevitable, over which we still have some control, and either to deflect them or to alter them as best we can.

Considering the future of Congress, he said, "There could well be some institutional change that seeks to deal with the vast amorphous public interest that is now underrepresented in Congress, perhaps the creation of some specialized institutional framework." This was a tantalizing seed of an idea that drew questions and speculation from the participants, but the form of whatever might grow from such a seed was undefined.

One possible clue to institutional change comes from the struggle in recent years over direct public participation in government affairs, an effort in part to fill the vacuum left by indirect routes of representation through the parties and Congress. Ruckelshaus views this trend toward greater public involvement in decision making as both important and hopeful, particularly in dealing with such looming and contentious risk issues as public health and safety and the environment.

"Starting in the 1960s and gaining force in the 1970s, we see the public's insistence on having a bigger piece of the action. They want to have more involvement in governmental decision-making processes, over which they feel they have little control and which they don't trust. We've seen that translated into statutory guarantees—right-to-know laws that are being passed in states at an accelerating rate, the Freedom of Information Act, Citizens' Right to Sue, and so on.

"The question in this country, then, is no longer over whether the public should be involved in these kinds of decisions. They're in. And in a democracy, once you let the public in on these decisions, it's very unlikely that they are ever going to get out. I think we should not resist this but figure out how to involve the public meaningfully. We can do this by giving them clear access and adequate information, and then forcing them to address the same social issues and trade-offs that the decision maker does. There are techniques that are slowly, glacially, becoming available that will allow us to do this. I think it is inevitably coming, and the quicker we adjust to it the better."

The concerns for control and self-reliance, detected in Yankelovich, Skelly and White surveys, and expected to spread throughout the population in coming decades, would seem to reinforce this drive for active involvement on the part of the public. Whether this will coalesce into a distinct political voice or whether it will be assimilated by one or both of our existing political parties remains to be seen.

While Congress has grown weaker in recent decades due to the demise of our parties, the other branches (particularly the judicial) have grown bolder in many ways. Turning to the Supreme Court, Ruckelshaus pointed to the historical anomaly of the Warren Court and the impact it has had and continues to have on American politics. "For the first time in its 200-year history the Supreme Court under Warren was suddenly out in front of the other two branches of government in fostering change, and as a direct result of its decisions on desegregation, busing, prayer, pornography, and abortion, we have seen the religious right enter our political system and now struggle for dominance of the Republican party.

"But with the advent of a more con-

> "Economic regulation, we'll have less. Social regulation—that is, regulation to protect health, safety, and the environment—we'll have more. Social regulation may shift to the states, but I don't see any diminution, and the reason is public opinion, particularly where involuntary types of risk are being imposed."
>
> *William Ruckelshaus*

servative set of justices under Rehnquist, Scalia, and O'Connor, we can expect the Supreme Court to pull back from this historical excursion into change making. Social pressures may well diminish as a result, but we should not be fooled into thinking the new Supreme Court will dismantle things. It is the conservative tendency not to change what is established. If anything, the new court is likely to have a locking-in effect."

Ruckelshaus believes the conservative tendencies of the Supreme Court will leave the statutory-regulatory base established at such places as EPA, where he was twice administrator, pretty much intact. Fifteen years ago, he points out, there was no statutory base at EPA; today there are 10 major statutes directing its mission. He believes that public attitudes toward risk and governmental protection are now fully embodied in these statutes and that public sentiment runs strongly against any reversal of their intent. The implication is that the legislative branch would also be unlikely to pull back from a protectionist role in these areas.

The broader message was that the conservative political leanings of the nation should not be misread to mean a uniform retreat by the federal government in all areas. Regulation, in particular, will be mixed. Ruckelshaus's prognosis draws a sharp distinction. "Economic regulation, we'll have less. Social regulation—that is, regulation to protect health, safety, and the environment—we'll have more. Social regulation may shift to the states, but I don't see any diminution; and the reason is public opinion, particularly where involuntary types of risk are being imposed.

"Essentially, where you have risks in the high-dread, high-uncertainty areas of public opinion, such as nuclear power and toxic wastes, the public demands an extraordinarily high level of government protection." He maintains that it is not enough to point out the much higher levels of risk from smoking, drunken driving, and so on. The public is just not interested in that. They will leapfrog probabilistic arguments, insisting that government aggressively address those risks for which they have a sense of high dread and high uncertainty.

Future political action is a little less clear-cut when it comes to the welfare issues. Ruckelshaus does not agree that we are witnessing the demise of the welfare state in the United States. He sees it more clearly as a time of moderation, of broad disenchantment with welfare programs, and a time of reassessment of the role of government in protecting the less fortunate. The current trend is toward less government reliance, more self-reliance. But political debate is notably lacking; perhaps we are in a lull until the public/private moral focus can be worked out by society or until the economic future of the United States is more certain. If the economic pie is not going to inevitably grow, allowing each person the presumption of a larger piece, the notions of how government redistributes income will have to be rethought.

One of most critical welfare issues ahead is the transfer of funds from workers to retirees. Ruckelshaus says flatly, "Social Security in 2006 will be different. There is no way we can continue at the current rate. When the baby boom reaches retirement, we will not be able to afford the kind of social security promises now implicit in the law. There are simply not going to be enough workers to produce enough wealth to make that level of transfer from one generation to the next."

The political question he sees is whether the social security problem will be left to drift or dealt with through gradual adjustment. "If we let it go, we could trigger some kind of generation warfare. We may push a whole generation of young workers into the voting stream in far greater proportions than we have seen historically. If there is a widespread perception of a major grab for resources by the elderly at that time, then a political clash of great proportions will occur. Recognizing the dimensions of the problem, I think something will come along to head it off."

In a related issue, Ruckelshaus foresees the possibility of intergenerational conflict over health care resources. Given the politically powerful elderly of the twenty-first century, "too much of our pool of available resources may go for such things as keeping a person alive for an extra year, as opposed to providing health care for people under the age of 15; right now, for example, over one-third of those under 15 have never been to a dentist." The implication of his remarks was that some new political balance between the old and the young will have to be found in the early part of the next century.

A great many political issues of the future will collide over the division of our finite economic resources. As on the personal level, our nation is coming to realize that we cannot have it all, do it all. Thus growing needs for health, welfare, and the environment will be competing with payments for the deficit, now the fastest-growing item of the federal budget, as well as the arms buildup. Defense, in the view of Ruckelshaus, may be one area for relief. "Here we have one-third of our budget, some $300 billion, going in large measure for weapons that will never be used no matter what happens, while other uses for those resources go begging."

Whether we can provide for all our needs will depend a great deal on the health of our economy, and that, in turn, will depend increasingly on how we adjust to the rapid integration of the global economy. Ruckelshaus points out that the internationalization of our economy will mean some loss of political control over our own affairs, that we will become less of an island unto ourselves, and that this, in turn, may run head-on into the growing concerns for control expressed by the new-collar workers, identified by Yankelovich, Skelly and White as being in the forefront of social change.

"This could well mean a call for more protectionism. We can either do that, erect more barriers to these foreign threats, or we can take the tough steps to adjust, understand the elements of successful international competition, and strive to be the low-cost, high-quality producer. Protectionism, which is just as likely an outcome as not at this point, would be ruinous; we would be lucky to reach 2006 in anything like our current form."

Our industrial policy, once championed to cope with international economic competition, was sacked five or six years ago on charges of socialism. Ruckelshaus feels the debate will reignite in the next few years. "In truth, we already have one. We have a fiscal policy, a tax policy, an antitrust policy, regulatory policies, a trade policy, and so on; we have literally hundreds of ways our government impacts our economy. The real problem is not that we don't have an industrial policy but that it is so uncoordinated. No one is looking at the cumulative impact of all these government policies on our economic system. I believe that debate over coordination of policy must take place and will take place." ■

Economics and Business

Speculating on economic matters, William Massy, vice president for business and finance at Stanford University, predicted that the predominant business environment in 2006 will be global and that the main economic agenda before us in the early part of the twenty-first century will be how to deal with a two-tiered world, how to bridge the gap between the have and have-not nations.

"World trade will be flourishing in 2006," predicts Massy, "as the real cost of transportation and communication continues to decline and as more and more countries are able to pull their weight in both production and consumption. India, Korea, and Brazil will have emerged as significant economic powers, as well might China if it stays on its present political course."

Japan, he believes, will undergo some fundamental economic change, because its population is aging even faster than ours. Its high savings rate will be seeking outlets through consumption just as its supply of labor gets very tight. The answer: "More imports," says Massy, "despite lingering cultural and political barriers. Large Japanese imports will not only help the U.S. balance of trade but will also stimulate and stabilize world trade generally."

Here at home, he predicts that the political issue of protectionism versus trade will hang in the balance for some time but that we will eventually opt for trade. "Trade," he explains "will win for three reasons. First, people will not give up their Toyotas and Sonys. Second, our own key industries will themselves need to export. And third, neither our politicians nor our economists will have forgotten that the Smoot-Hawley tariff of the early 1920s had a good deal to do with the onset of the Great Depression and the subsequent collapse of the democratic political system in Germany."

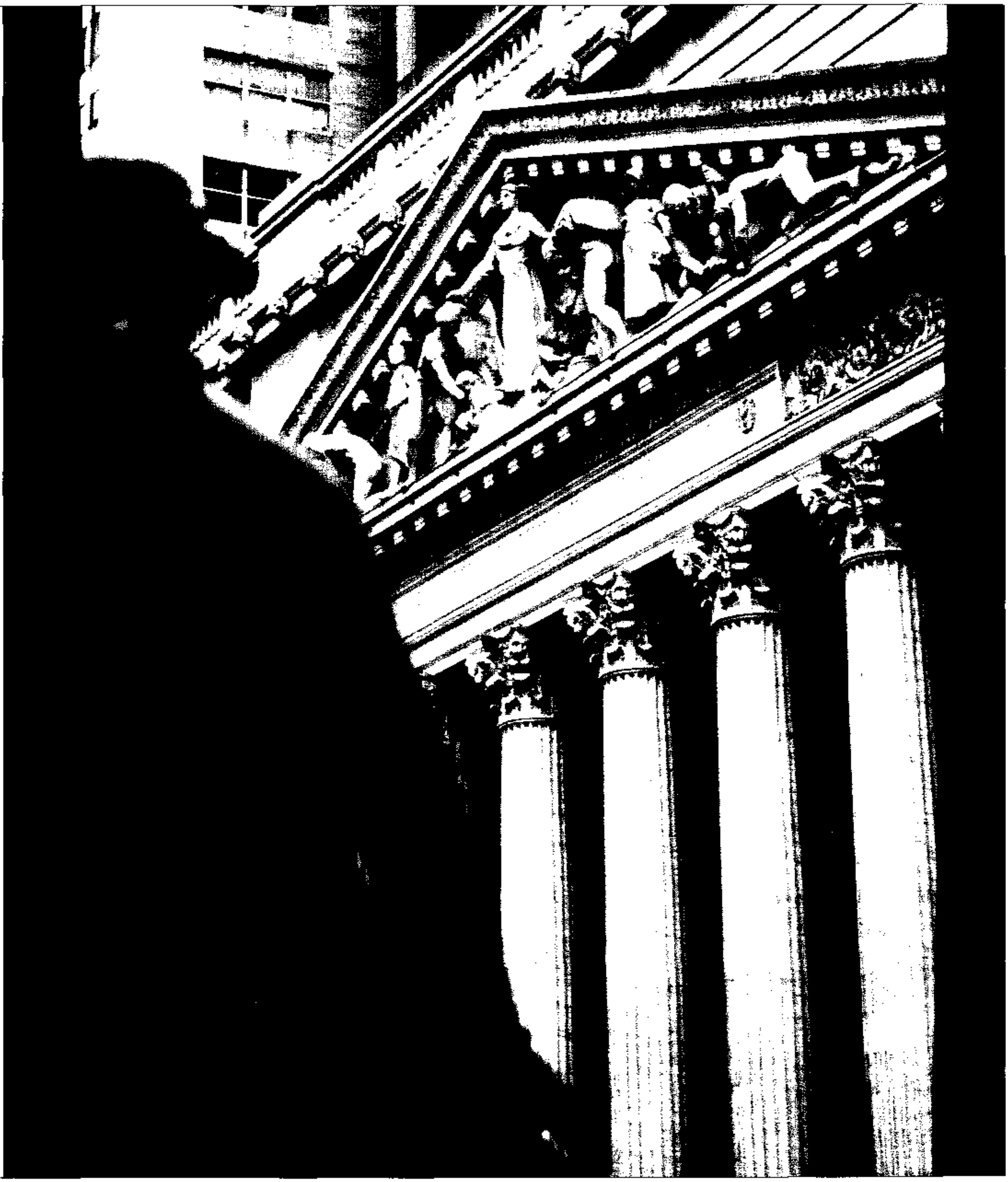
Assuming the United States and its trading partners can move beyond the temptations of protectionism and can find more innovative ways to protect jobs than to build fortresses around them, the prospects for the world economy are indeed bright. Much will depend on the United States, which in truth has not yet fully embraced the notion of its economy being internationalized or the prospect that jobs can and will flow as easily to Malaysia or Ireland as they do to North Carolina. Or even the converse, that with the right technologic and intellectual advantages, what was once seemingly lost can just as easily flow right back again.

The next two decades will be a time of adjustment for the United States and the West—a time to adjust to decreasing domination of the world economy and to adjust to replacing economic hegemony with a role of leadership among an expanding universe of economic powers.

The critical leadership issue will be that of formulating policy in a two-tiered world. The fruits of prosperity over the next two decades will be distributed unevenly, and many Third World nations, burdened by excessive population growth and economic stagnation, will fall further behind. Massy believes that we cannot long ignore the political strains of a growing gap between the haves and have-nots, and provides a sobering statistic that puts the rift into perspective: that the democratic industrialized nations' share of world population will shrink from 15% to 5% by 2006.

Citing Ben Wattenberg's *Demographics Is Destiny,* Massy says, "Ultimately, population has a major effect upon power. This will be masked for a long time by differences in economic and military strength per capita, but ultimately it will have to be taken into account."

Massy's prescription for helping to bridge the two-tiered world is free trade, a free flow of international capital, and an open door to the fruits of development. "We have got to resolve that we are going to compete, but not exclude, and send clear signals to the world that we will not deny opportunity. If we circle the wagons and deny access to development, it will only lead to insistence by those who are excluded to divide up what we have. We must align ourselves with change, for pragmatic reasons as well as moral reasons."



> **“** We have got to resolve that we are going to compete, but not exclude. If we circle the wagons and deny access to development, it will only lead to insistence by those that are excluded to divide up what we have. We must align ourselves with change, for pragmatic reasons as well as moral reasons. **”**
>
> *William Massy*

The hope, of course, is that nation after nation will lift itself up, emulating the successes of postwar Japan and Germany, of modern day Korea and Taiwan, Hong Kong and Singapore. Massy believes the resource base of the world is fully capable of sustaining the escalating new competition, saying that "the real resource issues will be control, distribution, and price."

He singles out agricultural resources as an area facing particularly sweeping change in the years ahead, with vast implications for agricultural trade. "Advances in biotechnology presage another revolution in agriculture. The introduction of these techniques will lead to major dislocations, as well as stunning increases in productivity."

He cites the example of using bovine somatotropin in cows to increase milk production. Currently moving through FDA approval, it could be on the market by late 1987; the likelihood is that 80–90% of the producers in the United States will adopt its use within three years. Estimates are that milk production will increase by 30%, that milk prices will drop 10–15%, and that the number of dairy cows and dairy farms may have to decline by 25–30% to restore market equilibrium. "We have here," comments Massy, "a microcosm of the accelerating effects of agricultural change upon the economies of the twenty-first century."

Massy regards domestic productivity as the "$64,000 question for the next 20 years. If we are going to compete in this world economy, we are going to have to become more productive, and that's going to depend on technical developments, the mix of economic activity, capital investment, and the sociopolitical scene. U.S. productivity has declined markedly in recent years for any number of reasons. I don't see our getting back up to the 3% per year annual increase in efficiency we once enjoyed. But if we can get back up to the middle one-percents, I think we will be doing very well."

Technology is one of the important drivers of productivity growth, and Massy sees "nothing more important during the next 20 years than the information revolution. Computers and telecommunications offer new functions, product variety, productivity leverage, and the opportunity for work enrichment." He views job enrichment as a not-so-obvious benefit of the information age, with implications for management style, labor relations, and of course, productivity.

"I see the information revolution reversing the division of labor that has been with us since the Industrial Revolution, permitting more integration of work elements and groups. The consequences of this for the office, as well as the factory, will be fully apparent by 2006."

The thought is that individuals with the help of computers will be able to do a much greater share of the specialized tasks formerly parceled among many. Jobs can be reconcentrated, with the result being a greater sense of ownership by workers and a greater sense of teamwork. With fewer people, highly motivated and highly integrated, productivity should climb, if not soar.

Massy sees this trend dovetailing nicely with the emerging management style he calls theory Z. Looking back, theory X (hierarchical management—the legacy of military organizations and heavy industry) was supplanted in the 1960s and 1970s with theory Y, participatory management. Voguish, it nevertheless suffered in reality from a continued division of labor and the too-many-cooks phenomenon. Theory Z he calls teamwork management. This translates in practical terms into the creation of quality teams, which span the organization from top to bottom and from area to area. Teams are created for a special purpose and have a finite life; and the inclusion of senior management ensures leadership and access to organizational resources.

"By 2006 the idea of organizational teamwork will have supplanted both theory X and theory Y and will be the dominant management and operational style in U.S. business. I'll go out on a limb of optimism here and say that better management know-how and increased personal responsibility of workers will, in fact, combine with technology to save U.S. manufacturing."

Massy, like others, sees the U.S. economic mix moving inexorably in the direction of services, "even though manufacturing will still be the key to U.S. productivity growth. By 2006 many manufacturing companies will have long since moved to vertically integrate service with manufacturing. They will have recognized that when a product is sold, the customer takes title and is responsible for use, whereas with services, the provider usually retains ownership of the product along with the ability to influence its use. Vertical integration to include service thus opens up additional opportunities for marketing, market control, and profitability."

It also opens up some pitfalls. Massy oversees some of the large service businesses associated with Stanford University, and on the basis of his experience, he cited two laws of service. "The first law of service is that satisfaction equals performance minus expectations. This means that companies not only have to control the quality of performance but also manage customer expectations. The second law of service is that it's hard to play catch-up ball. The service encounter is essentially transitory, with a whole lot of personal interaction. There is no time for gradual adjustment, as there is with a product; it is momentary and gone. It's very hard to retrieve a customer and change his or her attitude after providing a bad experience."

Massy suggests that the structure of our service economy in the future will proceed along parallel high-tech and low-tech lines. "We should have a comparative advantage over other nations in providing high-tech services, such as R&D, consulting, and investment banking, and a geographic advantage in serving a growing need for low-tech services here at home, such as maintenance, cleaning, and security."

The final building block of U.S. productivity is capital, and here above all, Massy feels we are sailing into smooth waters, away from what he calls the "anomalous times of the last 15 years. Capital should be readily available. Our postindustrial values and affluence should lead to sufficient savings and investment capital. Inflation should be moderate; we know how to deal with it. The tax system should be neutral; we are getting out of the investment business as far as our tax system goes. And real interest rates will drop back from the current 4–5% to their long-term value of 2–3%. Equities will sell at reasonable price-earnings ratios, relegating takeover mania to history."

In summary, according to Massy, by 2006 we will be faced with a choice. The worldwide economic domination by the West that has been going on since the beginning of the Industrial Revolution will be coming to an end. "The question will be whether to adapt, compete, and find new niches in the global marketplace, or to circle the wagons and fight a delaying action." ■

Science and Technology

The effects of science and technology on our changing present and uncertain future are asserted strongly by Robert White, president of the National Academy of Engineering: "My central thrust is that technology change is probably the most powerful long-term influence affecting business and nations. Technology is a forcing concept, but it operates on a time scale long enough to confound casual observation."

To advance his point, White refers to the long-term wave theory of economic development, first suggested by the economist Kondratiev in the 1920s, which attributes major cycles of economic growth to "great outbursts of technology changes so radical and sweeping that they completely transform society." According to this perspective, there have been four such cycles so far. The first, from roughly 1800 to 1850, centered on steam power and textile manufacturing; the second, from 1850 to 1900, centered on railroads and steel; and the third, from 1900 to 1950, centered on electric power, automobiles, and chemicals. The fourth, which we are now in, is dominated by computers, electronics, aerospace, pharmaceuticals, nuclear technology, and biotechnology.

"What history has taught us," says White, "is the power of technology to expand the world's resource base." We are still experiencing tremendous resource expansion as a result of the third technology cycle. We have entirely new materials in the form of ceramics, plastics, and composites. Thanks to better extraction technology, we have more usable iron ore today than we did 50 years ago. And innovative methods of generating more electric power from a more diverse fuel base have, at least for the moment, taken the edge off the energy crisis.

White predicts the power of technology to unlock resources will be even greater in the current technology revolution and singles out information technology and biotechnology as the embodiment of this cycle. "These areas will be as sweeping in their implications as anything in the past two centuries. They represent a new understanding at the most fundamental levels and offer the ability to manipulate physical and biologic systems to produce goods and services and to control natural processes. The information revolution, which is now in full stride, already permeates the whole of society. Biotechnology is certain to have similar widespread effects, but its day has not yet come. It's only a question of time.

"Information technologies—centered on computers, communications, and the microchip—are already transforming the most basic functions of society: food production, industrial production, and human health services. Hardly any facet of the lives of individuals, industry, or government is unaffected. New industries are being spawned, and ways of working and living are being radically altered. They are resulting in a shift of leadership from older firms to newer, higher-tech firms, and from one country to another."

White believes the information revolution will transform the world in three basic ways: (1) it will help merge technologies, (2) it will accelerate the global diffusion of techology, and (3) it will accelerate the movement of labor from physical to mental pursuits. "The information age is a time when technologies come together," says White. In the near future, he sees materials and computers coming together to produce automated manufacturing systems; biotechnology and information technologies merging to produce new realms of medical care and agricultural systems; and civil engineering, nuclear technology, and information systems combining to produce the automated, robotized power plant. The information revolution will thus be a spur to industrial productivity, providing a competitive edge in the global marketplace. The impact on manufacturing will be particularly dramatic. White cited studies showing the use of robots is likely to reduce employment in manufacturing activities from 20% of the U.S. workforce currently to 5% by 2006.

"These areas will be as sweeping in their implications as anything in the past two centuries. The information revolution, which is now in full stride, already permeates the whole of society. Biotechnology is certain to have similar widespread effects, but its day has not yet come. It's only a question of time."

Robert White

The institutional impacts will go even further than this. "We will see evolving in the decades ahead a growing decentralization of production systems, a decentralization that is already apparent in the ability to move production systems to locations abroad while retaining centralized management. The information revolution is transforming the shape of multinational corporations, the energy industries, global financial systems, and relations among many nations.

"In the new age," he predicts, "intellectual power will become the key resource, and corporations will seek out intellectual power wherever it may be located in the world. They will, for example, do their research and engineering wherever it can be done most cost-effectively."

This intellectual power will be strongly leveraged by advances in computer science. Despite their already sweeping influence, White views computers as still in their infancy and foresees computers of such power that they can emulate higher levels of human mental activity. Such machines, with the addition of artificial nervous systems based on a variety of microminiaturized sensors, will be able to understand speech, perceive their environment visually and tactilely, learn from their mistakes, and interact meaningfully with the natural world.

But perhaps even more important than the development of such a superrobot is the ability to harness hundreds or even thousands of computers to work together on complicated tasks. With the ways of the world becoming more complicated in general, such capability will be vital for industries finding themselves having to deal with new problems. Concern over the environment, for example, has had a huge impact on the electric utility industry. For such problems, which deal with very complicated systems, ganging together large numbers of computers may be the only feasible approach; the atmospheric dynamics involved in air pollution, for example, have so many variables that even the most powerful computers have been unable to model what really happens.

These are tough questions for which we must turn to technology for answers. "No set of environmental issues approaches—in political and economic consequences—those generated by the production and distribution of energy," White points out. "Add together the issues of climatic warming from CO_2 and trace gases, acid rain, and SO_x and NO_x emissions on the fossil fuel side—and the catastrophes of Three Mile Island and Chernobyl on the nuclear side—and you see that the electric power industry faces what must be the most difficult set of public policy issues today related to use of modern technology."

By 2006 White suggests we will have resolved through research, regulation, and control most of the fossil fuel issues related to SO_x, NO_x, and acid rain, and we will have narrowed our focus on the greenhouse effect, perhaps the largest and most protracted of all the environmental problems. Calculations indicate a doubling of CO_2 by 2050, bringing about an increase in the average temperature at the surface of the earth of 3–8°F. Trace gases will speed the process.

Drawing on his expertise as an atmospheric scientist, White says, "On the basis of what we know about seasonal changes, we can expect, as a first order of generality from this warming, more northerly storm tracks and reduced rainfall—with significant impact on agriculture—at the latitudes of the United States.

As a domestic political issue and a geopolitical issue, the portent of global climatic change may prove to have few equals in the early part of the twenty-first century. The problems will be compounded by large scientific uncertainty and the fact that the climatic impacts will be distributed unevenly. "There are certain to be winners and losers," says White. "Russia, China, and Canada could all be beneficiaries with, for example, extended growing seasons and abundant water. And the effect may even be beneficial in some regions of the United States. We just don't know enough yet to predict the regional impact."

What to do? As White points out, "CO_2 is an inherent product of fossil fuel combustion, and as long as this is what we burn, the increase in CO_2 is inevitable." Without a clear and present danger and without clear scientific understanding, debate over the next decade or two is likely to revolve around the feasibility of long-term policy options, nationally and internationally. Several were presented at the seminar, as the CO_2 question sparked extensive discussion among the participants.

White suggests, as a prudent first course, moving toward benign forms of energy and retaining the nuclear option. In the strongest possible words, he said, "Another Chernobyl must be avoided. Whatever it takes! Otherwise, we will foreclose the nuclear option." A second policy course would be to simply adapt to climatic change over a hundred years or so. White continues, "The real problem of adaptation would not be temperature but water. If we want some indication of the human tragedy associated with drought we need look no further than Africa."

William Nierenberg, director of Scripps Oceanographic Institute and former chairman of the Committee of the National Academy on Climate Change, suggests as a long-term course of action that we shift our fuel economy to methanol made from cellulose. "It's a universal fuel, renewable, and wouldn't increase the CO_2 level because the plants grown to produce the fuel absorb enough CO_2 to keep the atmospheric load in equilibrium. We have enough biomass to make it feasible. The numbers come out about right."

Wolf Haefele, chairman of the board, Kernforschungsanlage Julich GmbH, proposes a transition to carbonless fuels over the next 100–150 years. "We can conceive a very simple energy system using hydrogen and electricity as secondary fuels, generated on the primary side by nuclear and solar. To do this we would have to change the entire energy infrastructure, and time then becomes the crucial element—it's not prudent to count on such a modern energy system in less than 100–150 years. Meanwhile, if further uses of the carbon atom were made flexible so that the carbon atom could be gradually replaced by the hydrogen atom, we would truly have an answer to the CO_2 problem."

The Cool Water coal gasification–combined-cycle power plant now operating on the Southern California Edison Co. system is portrayed by Haefele as the kind of horizontally integrated fuel process that could be modified to help move the world toward a carbonless fuel future. For its environmental attributes, Stewart Udall, attorney at law and former secretary of the interior, extolls Cool Water as "the most significant technical development in the energy field since WW II. Who, 15 years ago, would have thought that the cutting edge of energy technology in 1986 would be coal?"

The point was not missed that the greenhouse effect, like many other modern problems, is a technical problem looking for a technical fix. Building a system for one purpose and then rebuilding it for another purpose has a certain inelegant, patchwork quality about it. Haefele seems to point to the twenty-first century when he says, "Technology should no longer remain tied to single objective solutions. We're paying too high a price for it. It should become multiobjective in nature and development. It should become coherent, synthetic. This would automatically take care of the imbedding of technology in the environment and the bigger question of the interface between technology and society. The dichotomy would disappear."

White's notion of the information age affording synthesis among technologies would seem to be a necessary and crucial step toward developing multiobjective technologies of the twenty-first century. He sees research and education as the twin pillars of technical leadership that will get us to the new age. ■

THE WORLD OF 2006

Epilogue

The seminar cast some light on the forces and direction of the next two decades, but no one walked away with a clear view of life in 2006. Everyone was too aware of the possibilities for change on a personal, national, and international level to feel settled with a single view of the future. And most were just too aware of the role of the unpredictable and the unforeseen in shaping the history of the twentieth century.

Nevertheless, barring war or collapse, it seemed a near certainty to everyone that the single most important event in the next two decades will be the globalization of the world economy. This will not only affect our trade, foreign relations, and the balance of power but eventually every job and every household in America. In this way, internationalism will take on new meaning at a personal level, and new adjustments in attitude and practice will have to be made.

But in a larger sense, the global economy underscores a potent force that will be operating in the world over the next 20 years: a growing trend toward decentralization. The new information technologies are linking the world into an economic-neural network, diffusing decision making, stimulating the instantaneous flow of international capital, and spurring the fragmentation and worldwide migrancy of production units.

Over the next 20 years hierarchical management is likely to recede, and the enhanced flow of information and ideas will stimulate both democratizing forces on the political level and market forces on the economic level. The broad trend toward decentralization will be more obvious as the economic balance of the world shifts. Economic domination by the West will pass by 2006 as a new constellation of economic superpowers, particularly those in Asia, emerges.

Coordination will become a watchword among the array of economically powerful nations of the early twenty-first century. Interlocked and interdependent with all parts of the globe, we will discover new vulnerabilities. Shocks and turbulence anywhere will be felt everywhere. And issues once local will have become international—issues as far ranging as protectionism, unemployment, weather, health, aging, TV programming, information access, technology control, and welfare.

The basic struggle will be over international decision making, finding a way to forge consensus without relinquishing sovereignty. The result is that nations probably will have to give up a certain measure of sovereignty, as we are already observing in the economic sphere. The stresses inherent in attempting to cooperate with countries that have mutually exclusive national interests are likely to result in a new cycle of centralization of authority, this time perhaps manifesting that most-elusive of political ideas: world government.

Few issues will engage the world of 2006 as much as the disparity between the have and have-not nations. Close-knitting of the globe will make it difficult and impractical, if not dangerous, to ignore the problem as readily as is done today. Rapid economic development of the have-nots would seem to be the safety valve, but this could well create continuing job obsolescence in older manufacturing environments. The conflict between helping one's neighbor and preserving one's job has an ethical dimension to it, and at least in the United States, where a similar two-tiered structure is becoming entrenched, it could become one of those pivotal economic issues around which our moral focus seems to shift every generation or so.

Another genuine testing ground of international decision making will be the emergence of global environmental issues, such as the greenhouse effect. Because of the portent of climate change and redistribution of the world's water supply, this issue has great geopolitical significance. It may well flare the passions of the world as no environmental issue has in the past. And efforts to solve it, to control the CO_2-producing technologies or the climate itself, will lay bare one of the largest issues of modern times: the use and restriction of new technology.

It is technology itself that is speeding change, allowing the world to close in on itself, while simultaneously opening vast new resources and capabilities. Social change is not the least of the frontiers extended by technology. In the very long haul we may well see today's struggle over the risks of technology—from chemicals to nuclear power to computers—as a necessary prelude to the future. We could think of today as presenting an environment for social learning, a time for society to work through its issues of fear, control, and trust and to find new mechanisms for coping with the unknown.

This may give us some breathing room to develop a new type of scientific literacy that will allow us to deal with the far larger issues ahead of us. The capabilities of the coming biologic age will present us with ethical and social choices that will make today's struggles look quite innocent by comparison. And beyond 2006, we can only imagine what will transpire when the two great revolutionary streams of modern technology—information and biology—eventually meet and transform one another and us in the process. ■

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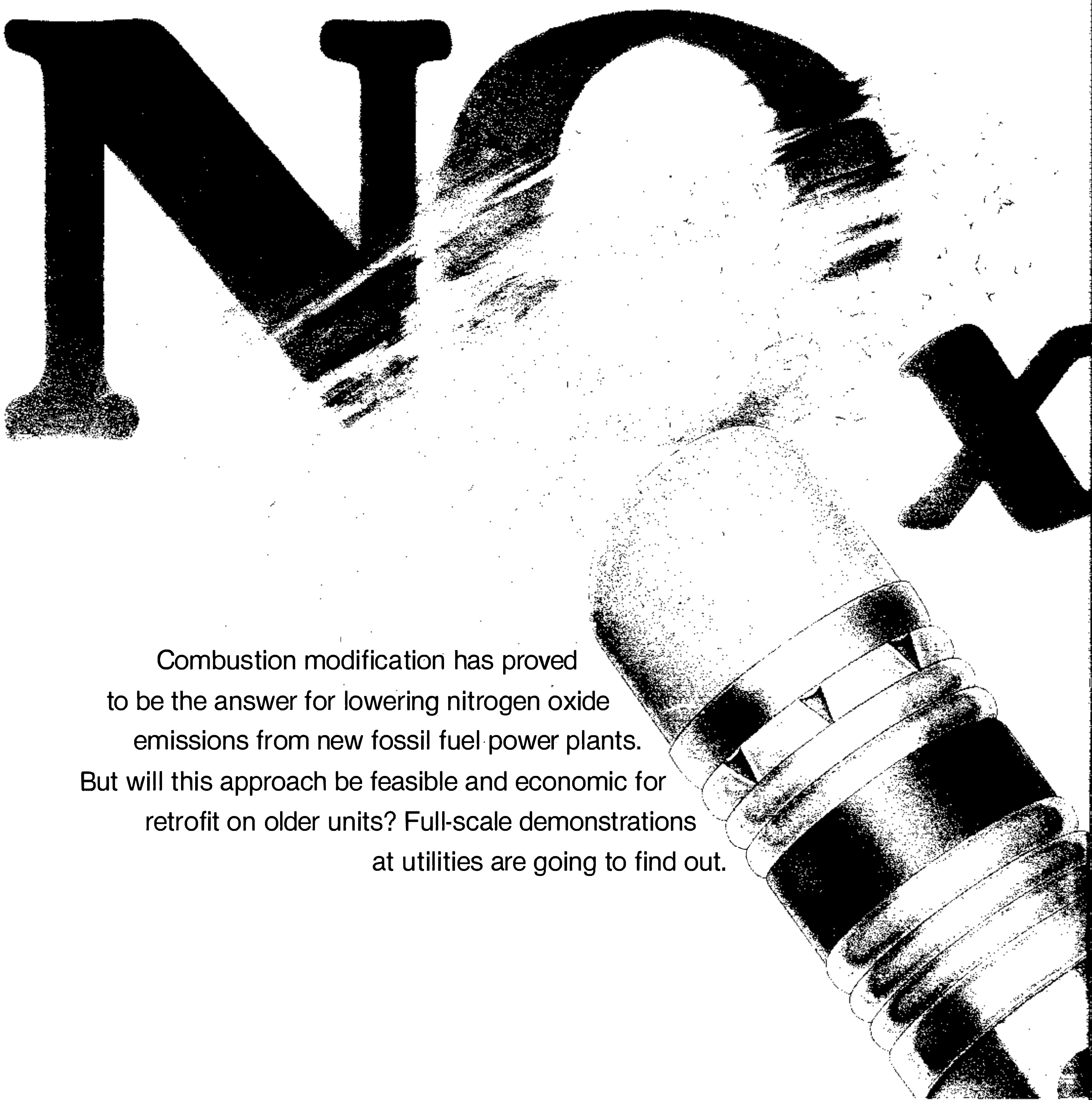
Retrofit Strategies for NO_x Control



Combustion modification has proved to be the answer for lowering nitrogen oxide emissions from new fossil fuel power plants. But will this approach be feasible and economic for retrofit on older units? Full-scale demonstrations at utilities are going to find out.

Produced in approximately equal proportions by emissions from vehicles and stationary sources, nitrogen oxides (NO_x) became an environmental issue in the late 1960s and early 1970s because of their role in atmospheric visibility, photochemical smog, and possible health effects. Regulations enacted during the next decade led to significantly reduced amounts of NO_x emissions from both new vehicles and new boilers.

"Now there is evidence that NO_x may be an important contributor, along with sulfur dioxide, to acid deposition and associated forest damage," according to Robert Carr, director of the Environmental Systems Department in EPRI's Coal Combustion Systems Division. "As a result, we and the utility industry are sensitive to the possiblity that this may lead to additional control requirements for both new and existing sources. Our priority at EPRI is to make sure that utilities will have the flexibility of applying a variety of NO_x reduction technologies to achieve effective control at the lowest possible cost and with the highest possible reliability."

Proposed legislation, already introduced in Congress, includes requirements for retrofitting abatement technologies on fossil-fuel-fired plants built before the New Source Performance Standards (NSPS) went into effect in 1971. The largest share of costs associated with new regulations will probably be apportioned to the electric utility industry, which produces just under one-third of the total national NO_x emissions. A key reason for this cost burden is that a large fraction of current fossil-fuel-fired generating capacity was installed prior to 1971. Although oil- and gas-fired units would also be affected by new NO_x legislation, pre-NSPS coal-fired units account for almost 85% of present utility NO_x emissions.

So far, NO_x reduction in U.S. power plants constructed after 1971 has relied on larger furnaces incorporating combustion modification (such as low-NO_x burners and overfire air), and this approach has proved quite satisfactory for new plants. More than 135 such low-NO_x boilers have now been built, involving a cost penalty of only about $5/kW, or less than 0.5% of total plant cost. Capital costs for retrofitting combustion modification technologies on older plants are anticipated to range from roughly $3 to $33/kW, depending on the level of control, type of boiler, and specific site characteristics.

The other option for controlling NO_x emissions is to clean up the flue gas before it leaves the stack. The only flue gas treatment currently in commercial use—selective catalytic reduction (SCR)—is significantly more capital-intensive and involves higher operating and maintenance costs than does combustion modification. Capital costs for SCR on a new plant range from about $50 to $100/kW, and SCR retrofits are expected to cost even more.

There has been some success in lowering the cost of SCR in other countries, primarily through increased catalyst life. Even if the economics improve significantly, however, the utility industry will have an enormous financial incentive to demonstrate combustion modification technologies.

There are four principal boiler types now being considered for retrofit NO_x control: tangentially fired, wall-fired with circular burners, wall-fired with cell burners, and cyclone. Pilot-scale tests of combustion modification technologies have already been successfully completed for all these types except cyclones. Also, a positive preliminary assessment has been reported on technology related to cyclone boilers. Full-scale demonstrations of these technologies in actual utility boilers will be needed, however, before they can be confidently considered for widespread use. EPRI is now launching such a demonstration program, scheduled for completion by 1991, involving combustion modification technologies that can be retrofitted on all four major pre-NSPS boiler types.

Demonstrations needed

"Although the pilot-scale testing of retrofit combustion modification has been very promising, there are still important questions about how cost-effective and reliable these technologies will be in full-scale utility boilers," comments Program Manager John Maulbetsch. "Combustion modification essentially lowers oxygen availablility in one part of the combustion zone while raising it in another.

"Such shifts can strongly affect overall efficiency, carbon burnout, and exit gas temperature—all of which we want to maintain within appropriate limits. In addition, we will have to minimize the potential slagging and corrosion on internal furnace surfaces exposed to a richer fuel mixture."

Many of these issues cannot be addressed at pilot scale. Also, much of the pilot-scale research has involved single-burner tests conducted in special facilities; actual utility boilers, however, have multiple-burner arrays, with as many as 50 burners, so the scale-up involved in commercial demonstration will be substantial. The demonstrations EPRI is now launching will involve a separate, two-year program for each of the four major boiler types. These demonstrations will generally focus on showing how well retrofit combustion modification technologies can reduce NO_x emissions on a long-term basis, determining what effect such systems have on other plant operations, and helping to pin down realistic cost estimates for commercial applications.

Each demonstration will require close cooperation among four parties. EPRI will select host sites, provide general coordination, and manage testing contracts. Host utilities and boiler manufacturers will share the cost of fabricating and installing the retrofit equipment. A test contractor will coordinate and perform the full-scale testing and evaluation.

In the area of emissions, researchers

will specifically be trying to establish which factors contribute to the optimal function of combustion modification systems in existing boilers and what effect, if any, they will have on other emissions control equipment. Operations measurements will focus on how well plant operators can control flame stability after introducing low-NO_x burners and on how such burners affect load following, combustion efficiency, and the ability to run a plant at partial load.

Assessment of financial impact will primarily involve determining the capital costs of retrofitting controls on older boilers and finding whether changes in plant O&M will lead to cost penalties. Retrofits could actually lead to better performance, if the burners being replaced have deteriorated or are outdated.

In each demonstration, a baseline of NO_x emissions will be measured on the unmodified plants "as found." Next, the boilers will be tuned for minimum NO_x production, to establish an optimal baseline for comparison with postretrofit emissions. Following retrofit of the new burners, tests will be made to see how much NO_x can be reduced through combustion modification and what effect this will have on plant operations.

Combustion modification

Underlying these proposed demonstrations is the fact that NO_x formation depends strongly on furnace gas temperature, the fuel-air mixture, and furnace fluid dynamics. Even small modifications in the combustion process can greatly influence emission levels. Combustion modifications to reduce NO_x are generally based on promoting a more gradual mixing of fuel and air to reduce flame temperature and on use of a richer fuel-air mixture to reduce oxidation of nitrogen in the fuel.

Such modifications begin with burner designs that control the initial mixing of fuel and air. Changes in other parts of a boiler downstream from the burners can also modify combustion by separating it into discrete stages. NO_x created in the initial flame, for example, can be destroyed by reburning in a second combustion stage, created by injecting a small amount of fuel above the primary combustion zone. Alternatively, a fuel-rich primary flame can be combined with a second stage in which overfire air (OFA) is introduced through ports above the burners, completing combustion.

Much of EPRI's work on NO_x reduction has focused on development of low-NO_x burners through joint projects with boiler manufacturers. Such modified burners can generally reduce NO_x emissions by 40–60% at pilot scale, with anticipated capital costs for retrofitting of $3–$15/kW. Combining low-NO_x burners with reburning or OFA can reduce NO_x by as much as 75%. The capital cost of adding OFA or reburning can vary in a range of $15–$33/kW, depending on boiler design and size.

Operating costs for combustion modification are anticipated to be negligible, except for reburning, although full-scale demonstrations will be needed to establish firm costs. If coal is used as the reburning fuel, additional operating costs are about 2 mill/kWh. In some units, however, oil or gas may be required when available residence time calls for a faster-burning fuel, resulting in additional operating costs as high as 13 mill/kWh.

To provide the greatest effect on total NO_x emissions, EPRI has chosen to concentrate its retrofit demonstration efforts on the four most common types of pre-NSPS boiler. Although these boilers vary considerably in their inherent degree of NO_x production, together they account for more than 90% of total NO_x emissions from pre-NSPS coal-fired utility plants.

The first demonstration of the proposed series, scheduled to begin during the spring of 1987, will involve the most prevalent of the boiler designs—the tangentially fired boiler—which accounts for 42% of pre-NSPS generating capacity. This design also has the lowest inherent NO_x emissions (0.4–0.9 lb/MBtu) because burners are aimed slightly off-center to create a rotating fireball pattern in which coal particles have a relatively long residence time. EPRI studies have shown that the pollution-minimum (PM) burner, developed by Mitsubishi Heavy Industries and licensed in the United States by Combustion Engineering, Inc. (C–E), can be retrofit on older tangentially fired boilers, and this is the basic approach for the demonstration. NO_x reductions of 45–60% have been demonstrated in pilot-scale tests on the PM burner in conjunction with overfire air.

This first demonstration will be carried out on a 350-MW (e) boiler at KPL Gas Service's Lawrence Energy Center near Kansas City. C–E will install PM burners with OFA at the plant. The results of this project may be the most telling of the series. "This burner has the potential of producing the lowest NO_x emissions of any burner modification," reports Project Manager David Eskinazi. "Because tangentially fired boilers are already the lowest emitters, this demonstration will help us establish a lower bound on achievable NO_x reduction via low-NO_x burners for retrofit."

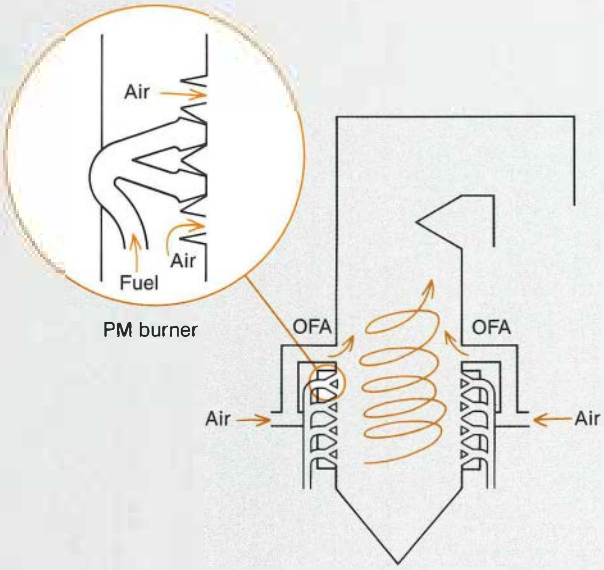
The second demonstration will focus on wall-fired boilers with circular burners. A boiler of this type will be retrofit with low-NO_x burners and OFA at the Homer City (Pennsylvania) power station, jointly owned by Pennsylvania Electric Co. and New York State Electric and Gas Co. The 600-MW (e) boiler is a supercritical unit manufactured by Foster Wheeler Energy Corp. "This plant was selected for demonstration because it represents a 'worst case' from the standpoint of high heat release rate," explains Eskinazi. "The high heat release rate results in high NO_x emissions and poses special retrofit constraints."

Such wall-fired boilers with individual circular burners produce NO_x emissions over a wide range (0.6–1.5 lb/MBtu), depending on unit-specific operating conditions and size. Pilot-scale tests have re-

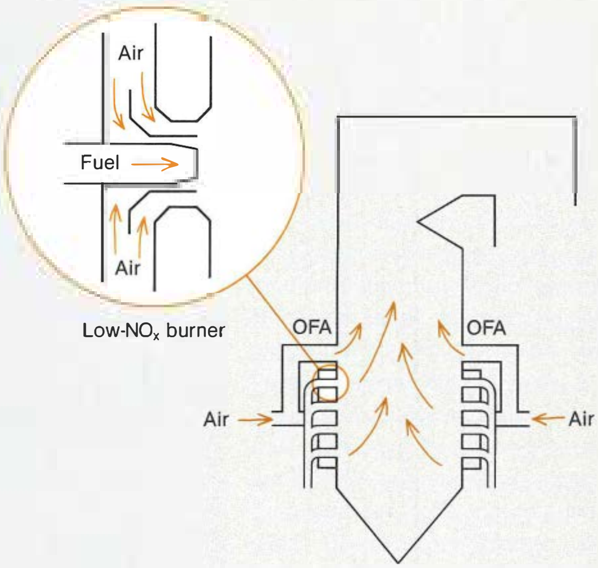
Retrofitting the Boilers

Reducing NO_x formation in utility boilers generally involves modifications that both lower combustion temperature and ensure a rich fuel-air mixture. Because boiler geometry has a strong influence on these factors, each boiler type requires a different approach—new burner designs, addition of overfire air (OFA), reburning above the primary combustion zone, or a combination of these concepts.

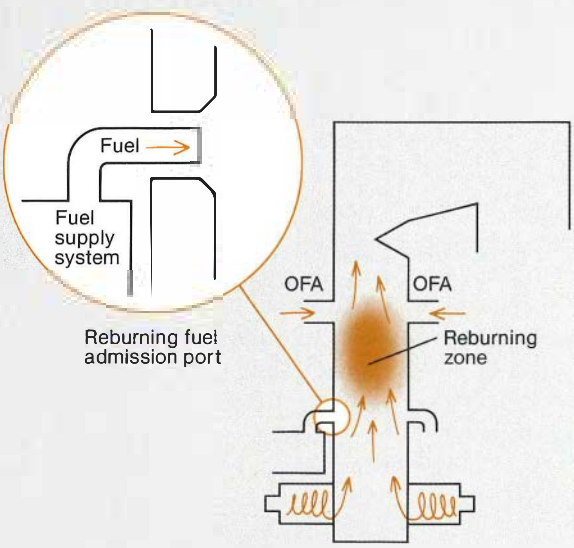
Tangentially fired boiler—*retrofit with PM burners and OFA.*



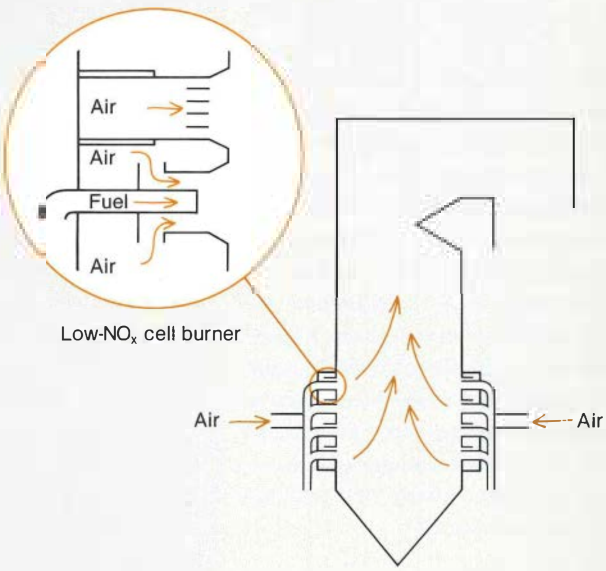
Wall-fired boiler with circular burners—*retrofit with low-NO_x burners and OFA.*



Cyclone boiler—*add reburning ports (with reburning fuel supply system) and OFA.*



Wall-fired boiler with cell burners—*retrofit with low-NO_x cell burners.*



sulted in NO_x reductions of up to 50–60% for this type of boiler, using low-NO_x burners.

Two more demonstrations are also planned, one for wall-fired boilers with cell burners and the other for cyclone boilers. Host utilities for these efforts have not yet been selected, but participants are now being actively solicited.

The concerns for this second pair of demonstrations again are based on type-specific characteristics. Wall-fired boilers with cell burners produce relatively high NO_x levels (1.0–1.8 lb/MBtu). These boilers were manufactured in the 1960s by Babcock & Wilcox Co. and combined two individual burner nozzles into cells that produced a high-intensity flame. Circular burners developed for wall-fired boilers cannot be used directly in these cells because of the close proximity of the two nozzles. A joint EPRI–B&W research project has solved this problem by using only air in one nozzle of each cell to create low-NO_x, staged combustion at the burner. This configuration has shown up to 65% NO_x reduction in pilot-scale tests.

In cyclone boilers, combustion takes place in horizontal cylindrical chambers attached to the lower part of the main furnace cavity. Low-NO_x burner technology is not applicable to this furnace design, and the most promising retrofit option for NO_x reduction in cyclone boilers now appears to be reburning. EPRI recently sponsored a feasibility study with B&W to evaluate this option, and pilot-scale tests are now under way. For a majority of cyclone units, reburning is expected to result in NO_x reductions of about 50%. Despite the technical difficulties involved, finding NO_x reduction retrofits for cyclone boilers and wall-fired boilers with cell burners is considered especially important because these types of plants are prevalent where acid deposition is a particular concern.

A clear choice

The issue of NO_x pollution has been called a sleeping giant, because of the

The Flue Gas Approach

Some other countries have already begun moving toward use of flue gas treatment as an immediately available way to reduce NO_x emissions from stationary sources. In Japan, where a high concentration of industry in heavily populated coastal regions has led to aggressive regulation of NO_x, more than 6000 MW of coal-fired capacity now incorporates such controls in addition to combustion modification. In Germany, where forest deterioration has been blamed in part on NO_x pollution, a council of environmental ministers has promulgated NO_x regulations that will require flue gas treatment on 60,000 MW (e) of capacity, resulting in increased electricity costs of 3–10 mill/kWh.

Many methods have been tried in an effort to remove NO_x from flue gases, sometimes in conjunction with SO_2 removal. Without exception, these methods have proved quite complex and expensive, and all of them reduce NO_x emissions only at the expense of creating more liquid or solid wastes. Only a few methods applicable to utility coal-fired boilers have progressed beyond the laboratory stage of development.

The flue gas treatment system that has found most extensive application is SCR. This technology is being widely applied in Japan and is undergoing commercial demonstration in West Germany. Also, EPRI has sponsored extensive tests on a pilot-scale SCR system, using its Arapahoe Test Facility.

In utility applications, an SCR system is placed between the economizer and air preheater of a power plant, where temperatures are suitable for the chemical reactions involved. Inside the SCR system, ammonia is first mixed with flue gas and then passed through a catalytic reaction chamber. At the catalyst surface, NO_x is reduced by the ammonia to form elemental nitrogen and water. SCR systems generally reduce NO_x emissions by 50–80%, although 90% reduction has been demonstrated under carefully controlled conditions.

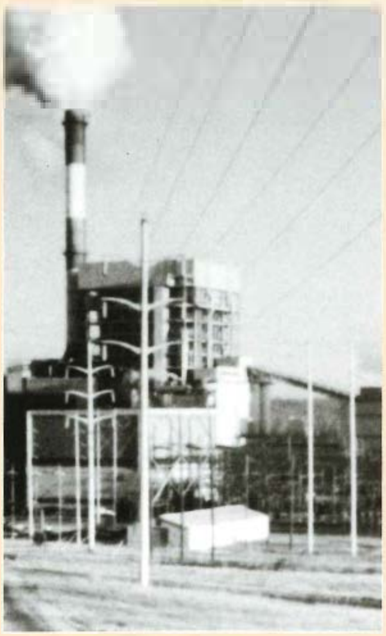
Overall costs of using SCR depend heavily on catalyst life. As the catalyst ages, the system allows more ammonia to pass through without reacting. Limits on this slip ammonia will likely determine how long the catalyst can be used. For two-year catalyst life, operating costs are estimated to be 8 mill/kWh, which would rise to about 14 mill/kWh for one-year catalyst life. Ammonia availability and cost is also a concern in the application of SCR.

One large uncertainty facing SCR use in the United States involves problems that arise from using high-sulfur coal—the type of coal burned in a large number of the U.S. plants that would be candidates for NO_x control. The same catalysts that promote destruction of NO_x molecules also encourage oxidation of SO_2 to SO_3, which in turn combines with slip ammonia to form solid and liquid sulfates. These compounds may then be deposited in the air preheater, where they may interfere with heat transfer, cause corrosion, and plug passages, increasing the pressure drop. Contamination of ash with ammonia by-products is also possible, which may increase waste disposal costs or hamper ash use.

These problems are less pronounced with low-sulfur coals typical of Japanese and West German applications. More research on these and other issues related to coal quality and differences between foreign and domestic operating practices is needed before the suitability of SCR technology is established for U.S. plants. □

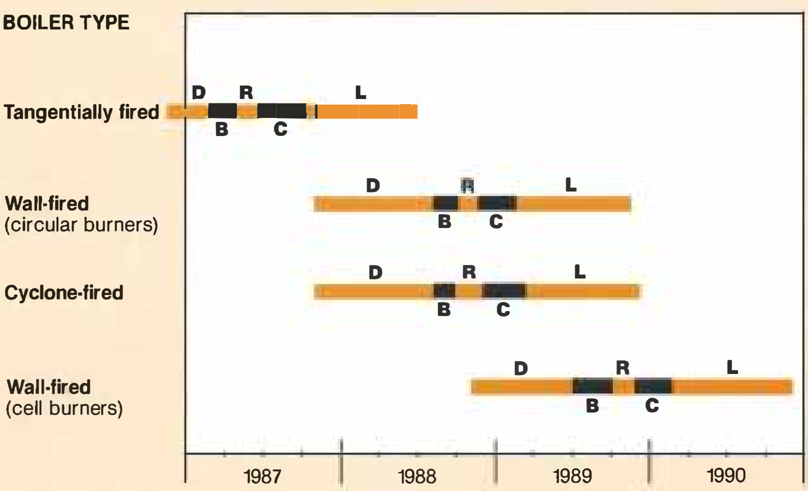
The Demonstration Plan

Each of the four low-NO_x retrofit demonstrations is expected to take about two years to complete. In the first of the series, modifications will be installed in a tangentially fired boiler at Kansas Power & Light Co.'s Lawrence Energy Center. The second demo, making the case for wall-fired boilers with circular burners, will involve retrofit of a unit at the Homer City power plant, jointly owned by Pennsylvania Electric Co. and New York State Electric & Gas Corp. Host utilities are still being sought for the final two demonstrations: modification of a cyclone-fired boiler and of a wall-fired type with cell burners.



Lawrence Energy Center

Homer City power plant



D: Equipment design and fabrication **R:** Equipment retrofit **L:** Long-term tests

B: Preretrofit baseline tests **C:** Characterization tests

huge costs that may be placed on electric utilities if they are forced to reduce emissions from older coal-fired power plants. NO_x is now assuming a much greater role in the acid deposition debate. As a result, regional emissions levels and air quality standards might be revised, which would leave individual states and utilities considerable leeway in determining which technology to use. Or specific quantitative emission limits might be set for each boiler, which could force some plants to use flue gas treatment or shut down altogether.

If combustion modification technologies suitable for retrofitting can be commercialized for all four major boiler designs, electric utilities would be provided with a relatively cost-effective means of substantially reducing NO_x emissions from their older coal-fired plants. Whether some plants would eventually require further NO_x reduction through flue gas treatment, however, depends on what specific environmental standards are adopted over the next few years. "Our goal is to rapidly confirm the NO_x reduction potential as well as the operability, reliability, and costs of combustion modification, so that utilities can begin making decisions about these technologies," Eskinazi says.

From a technical point of view, according to John Maulbetsch, the choice is clear. "Combustion modifications can reduce emissions significantly at much lower cost than flue gas treatment. In our demonstrations we are trying to show both utilities and regulators the benefits they could expect from retrofitting combustion modification technologies on older plants. Without this information, new emissions standards could well be set at levels that would preclude the most cost-effective solution to the NO_x problem." ■

This article was written by John Douglas, science writer. Technical background information was provided by Robert Carr, John Maulbetsch, Michael McElroy, and David Eskinazi, Coal Combustion Systems Division.


ROPER

Small improvements in design, materials, and components are yielding impressive efficiency gains for home appliances, which account for a full quarter of U.S. electricity demand. Proposed national efficiency standards could further trim appliance energy use, saving consumers and utilities billions of dollars.

Appliance Efficiency on the Fast Track

There is a quiet revolution under way in the kitchens and utility rooms of American homes. Residential appliances and space conditioning equipment, which consume 15% of the nation's energy and 25% of its electricity output, are becoming more efficient. The changes are not widely recognized, but they add up to big savings for consumers and to slowed demand growth and greater planning certainty for electric utilities.

Refrigerators present the most dramatic example because until recently they were the largest consumer of electricity in the residential sector and because they have shown a great improvement in efficiency. It takes 25 big power plants (25,000 MW) to run the familiar white boxes that keep the beer cold and the food fresh in American households. The most efficient mass-produced refrigerator/freezer (R/F) today uses half the energy of the average model 10 years ago, and further advances now in the prototype stage may lead to another halving of electricity demand in typical models of the 1990s.

Although refrigerators are showing a large improvement, other appliances, from water heaters to air conditioners, are also becoming more efficient. Some of the efficiency gain is in response to market forces like higher electricity prices and increased competition between natural gas and electricity. But much of the shift toward efficiency is due to appliance rebate programs offered by utilities and to efficiency standards that have been adopted in California and New York, and are pending in several other states and at the federal level.

Such standards set minimum efficiency levels for major home appliances and thus cause the average efficiency of the appliance stock to rise over time as old models are replaced. With nearly 35 million major appliances being purchased every year in this country, even small gains in the efficiency of new models can significantly reduce overall residential energy demand. If proposed federal appliance efficiency standards, which were endorsed by manufacturers, environmentalists, and the Edison Electric Institute in 1986, are enacted, they will (by some estimates) save consumers $28 billion on their energy bills over the next few decades and reduce peak electricity demand at the turn of the century by 22,000 MW, eliminating the need for tens of billions of dollars in new generating capacity.

Refrigerators lead the way

Energy consumption by refrigerators has varied widely over the past few decades, more than tripling from 1950 to 1972 and declining since then. The increase in energy use through the 1950s and 1960s was caused by a combination of factors. Refrigerators got bigger, growing from an average of 7 ft^3 (0.2 m^3) to about 17 ft^3 (0.5 m^3). New energy-consuming features were added, like automatic defrosting and true freezer compartments. As refrigerators were getting bigger and fancier they also declined in efficiency by about 40%, principally through reduced insulation in the walls and top of the shell and in part through reduced motor efficiency.

In 1972 refrigerator efficiency bottomed out and began to rise as energy prices skyrocketed and as California set mandatory efficiency standards and the federal government established voluntary standards. By 1984 the average efficiency of new models, accounting for the number of refrigerators sold in each product class, had risen by 66%, compared with the shipment-weighted average 12 years earlier.

The most popular R/F design today has a total volume of 16–18 ft^3 (0.45–0.51 m^3), with automatic defrost and a top-mounted freezer. A typical mid 1970s model now in use consumes 1500 kWh/yr and a typical 1987 model with the same features uses 1100 kWh/yr. The most efficient, new mass-produced model in this class consumes 750 kWh/yr, half of the 1970s' average, and costs $50–$100 more than a contemporary 1100 kWh/yr model. With electricity priced at $0.076/kWh (the national average residential rate), the 350 kWh/yr saved by the more-efficient appliance will pay for the added cost in two to four years and will then yield substantial savings to the consumer over its 15–20 year lifetime.

The efficiency improvements made to date have come not from one single dramatic change in R/F design but through a series of relatively simple and straightforward modifications. Fiberglass insulation has been replaced by more-effective polyurethane foam. More-efficient motors and compressors have been incorporated. The size of heat exchange coils has been increased. Better aerodynamic designs have been developed to allow for more-efficient air flow between the cold coil and the food compartments. And door seals have been improved, minimizing air leakage and reducing or eliminating the need for antisweat heaters around the rim of walls near the door opening.

Innovations on the horizon

Several additional measures now being demonstrated in custom models show that it is possible to build R/Fs considerably more efficient than the best commercial designs now on the market. Sun Frost, a small firm in Arcata, California, produces a 16-ft^3 R/F that uses about 230 kWh/yr, or one-fifth the energy of the average new mass-produced model with similar features. Sun Frost founder Lawrence Schlussler explains that his designs incorporate separate, top-mounted compressors for the refrigerator and freezer compartments, extra-thick polyurethane insulation, passive evaporators and condensers with no fans and large surface areas, and a shell design with no heat-conducting metal bridges between the inner and outer walls.

The Sun Frost products are expensive (about four times conventional models) but their operating costs are one-third to one-sixth the average. The higher cost is also a function of the small scale of the custom operation (up to a few hundred models sold per year). Most of Schlussler's clients have limited power sources like photovoltaic systems and thus need extra efficiency in appliances. Schlussler maintains that if mass-produced, models with the same features could be manufactured "for a price very competitive with conventional designs."

This claim is supported in a recent study conducted by David Goldstein and Peter Miller of the Natural Resources Defense Council. Goldstein and Miller calculate that with an additional investment in efficiency measures of about $330, a typical top-mount automatic defrost model consuming 1166 kWh/yr could be redesigned to consume 80% less energy. The energy saving would pay for the added cost in about four years.

Although most efficiency improvements simply reduce the energy needed to provide the same level of service, some innovations actually improve appliance performance. The lack of fans and use of separate, smaller compressors with less duty time make the Sun Frost models much quieter than conventional R/Fs. Moreover, the separate cooling systems for the refrigerator and the freezer actually make for better food storage.

One of the main reasons fruits and vegetables shrivel in a refrigerator or suffer from freezer burn is loss of water. In a conventional R/F the refrigerator section is cooled by the same very low temperature (−15°F; −26°C) coils that cool the freezer. The more air is cooled, however, the less moisture it can hold. As the air becomes drier it draws moisture out of the stored foods and deposits it as ice on the subfreezing cooling coils.

With separate systems, the air in the refrigerator is cooled by a coil that is above 32°F (0°C). As a result, humidity in the food compartment stays higher because moisture evaporating out of the food does not condense and freeze on the cooling coil.

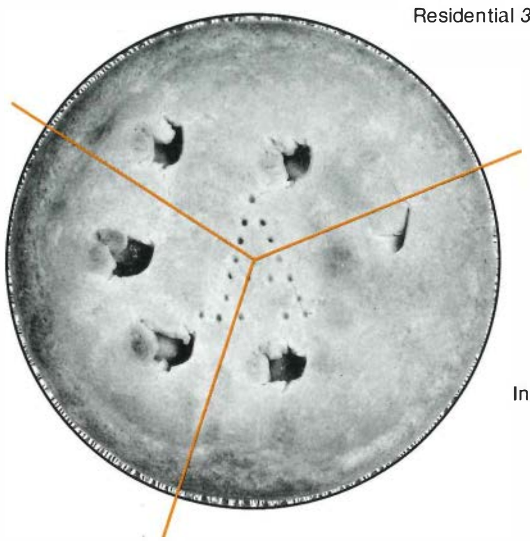
Because 50–60% of the typical R/F's energy demand is caused by unwanted heat gain through the shell of the appliance, improved insulation materials hold considerable potential for improving efficiency. Researchers at the Solar Energy Research Institute and Oak Ridge National Laboratory have been experimenting with several kinds of vacuum panels whose narrow (¼-in) cavities are filled with silica powders or glass fibers. Compared with the typical R-7 per inch insulating value of polyurethane foam, evacuated panels tested in the laboratory have exhibited an R-value of more than 100 per inch.

Questions have been raised, however, about the durability of these panels, as their high insulating value will decrease dramatically if their vacuum is lost. If the durability problems can be overcome, this high-performance insulating technique could have important effects on the energy and space efficiency of R/Fs. Replacing one or two inches of

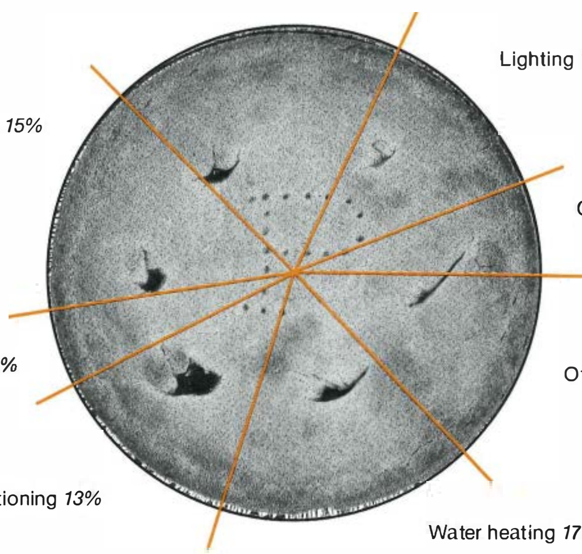
The Big Picture

American homes consume nearly 20% of the nation's energy and 35% of its electricity. Space heating and cooling equipment, water heaters, refrigerators, and freezers consume about 70% of the electricity used in most homes.

U.S. Electricity Use



Residential Electricity Use



foam insulation with a few tenths of an inch of the new material would enable manufacturers to provide about 20% more refrigerated volume without increasing the outside dimensions of the appliance. Conversely, smaller refrigerators could be designed that would hold more food than other models that take up as much space. Japanese manufacturers have reportedly been using evacuated panel insulation in some of their refrigerator models for several years. Little is known about their long-term performance, however.

High-performance insulation is not the only refrigerator efficiency modification still in the experimental stage. Alternative refrigerant mixtures have been proposed, particularly for dual-compressor systems. Such mixtures could conceivably trim energy consumption by up to 10%, say some investigators. Variable-speed compressors, used in less than 1% of American air conditioners and heat pumps but in about 40% of the Japanese models, have also been suggested for refrigerators.

Although many new efficiency measures show promise in laboratory and prototype models, Robert Johnson, director of product development engineering for Whirlpool Corp., cautions that making these innovations succeed in the mass market is not easy. "We are continually trying to increase the efficiency of our products, but we have to balance many other concerns at the same time, including size, features, durability, and price. Consumers expect a refrigerator/freezer to perform reliably for 15 to 20 years. Operating in that kind of market, we have to make sure that any changes we make will hold up for a long time. There's no question we can and will make our products more efficient, but it has to be an evolutionary process, and I just don't think it's realistic to think that we can shave 80% off our energy use (as Goldstein and Miller propose) and continue to provide reliable, competitive products."

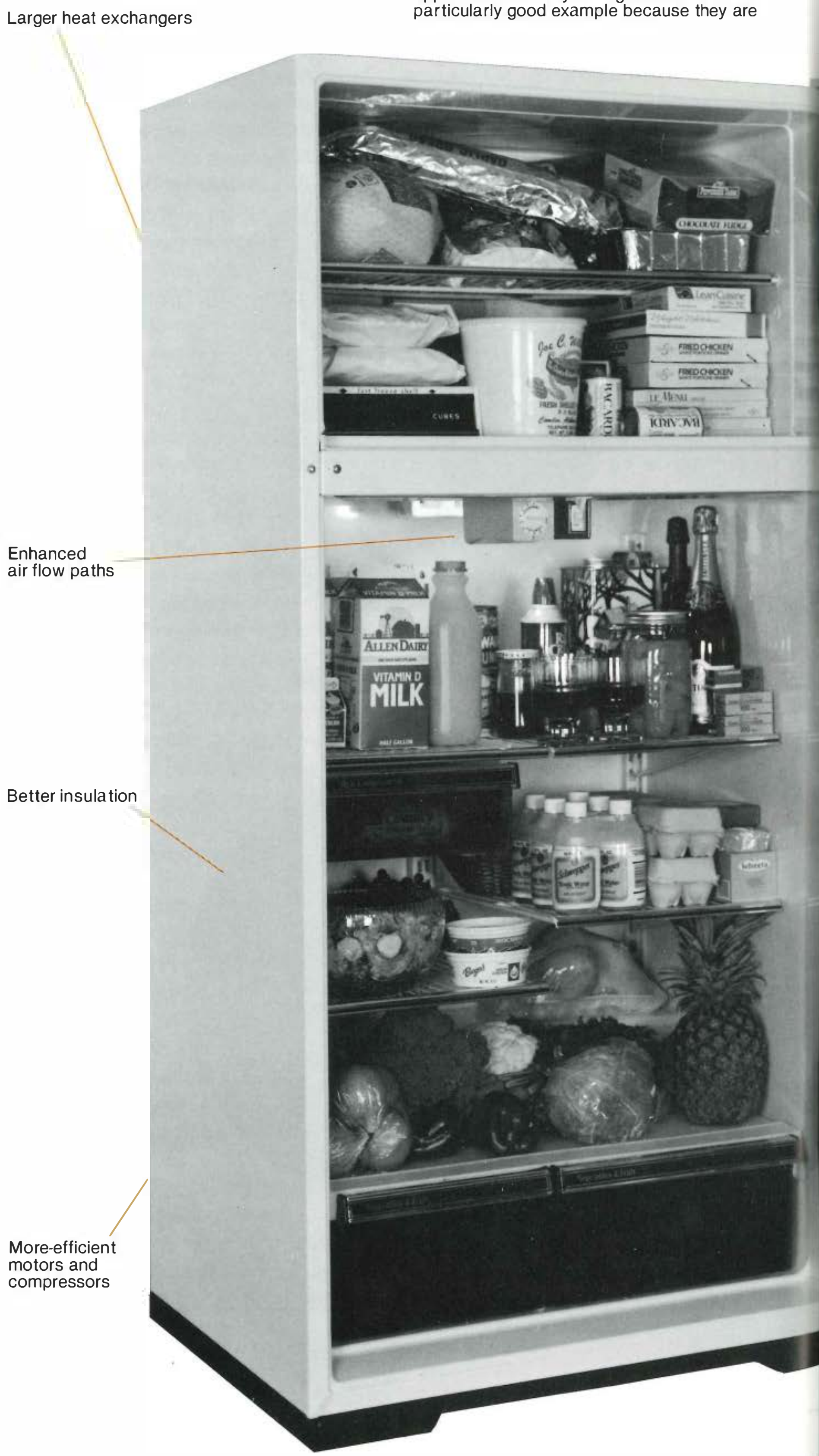
Johnson maintains that Goldstein and Miller are overly optimistic about the efficiency gains to be had from certain measures, and that they have not factored into their analysis some of the reliability and marketing issues manufacturers must consider. "Take double freezer gaskets. We've experimented with them but have found it very difficult to come up with a design that doesn't ice up and stick or make it difficult to close the door. Thicker insulation sounds good, but it either enlarges the size of the appliance or reduces the food storage volume. The thicker the foam, the longer it takes to cure, and that means large new investments in production capacity if we're going to keep making refrigerators at the same rate."

Johnson explains that superinsulation also raises some challenges with regard to compressor sizing. A small, efficient compressor may perform very well in a well-insulated refrigerator as long as the door is closed. But it may not be able to handle the load when a lot of food is suddenly introduced and the door is opened a lot. "We have to build machines that will suit the needs of all users," says Johnson, "including the family with six hungry kids right after they've gone shopping in Miami on a hot day. We can't use a compressor so small that it will take several extra hours to cool down their food. It's like automobile mileage," he continues. "You can build a car with a very small engine that gets great mileage on the straightaway, but it may not be able to climb the hills."

Despite these cautionary notes, Johnson agrees that many of the efficiency measures being proposed do hold commercial promise. "We're working on more-efficient fans, motors, and compressors, and we're experimenting with evacuated panel insulation and other innovations. Our product line is already nearly twice as efficient as the line we produced ten years ago and we expect to see substantial further improvement during the next few years."

Small Changes Add Up

Many small design and component changes are responsible for the gains being made in appliance efficiency. Refrigerators are a particularly good example because they are



one of the largest energy users in the home and because they have shown the greatest improvement in efficiency—more than a 66% gain since 1972.

Space conditioning efficiency on the rise

Refrigerators are not the only residential appliances that are becoming more efficient. Space heating and cooling technologies are evolving rapidly, driven in part by heightened competition between the gas and electricity industries.

The residential heating market has historically been dominated by gas-fueled appliances, but electricity is now making substantial gains in this area. One reason is the development of improved electric heat pumps. From 1976 to 1983, electric air-source central heat pumps gained 15% in efficiency. By 1984, heat pumps were being installed in about 30% of new residences.

Heat pumps are attractive for several reasons. They are more efficient than conventional heating technologies and they also provide air conditioning. Electric utilities like them because they offer the possibility of seasonal load management during summer peaks and strategic load growth in the winter. EPRI has a long-standing research program aimed at further increasing the efficiency and reliability of these devices, both for central heating and cooling and for individual room units.

Working with EPRI support, Carrier Corp. is developing an advanced heat pump employing variable-speed drive and integrated water heating that should reach the market in 1988. Performance targets for the new technology include a heating seasonal performance factor (HSPF) of 9 Btu/Wh, 40% better than the 1983 average HSPF of 6.4 Btu/Wh. The cooling performance target is to raise the seasonal energy efficiency ratio (SEER) 46%, from the 1983 average of 8.2 Btu/Wh to 12 Btu/Wh. And because the advanced model can use heat that would otherwise be rejected during the cooling season to heat water, it reduces the energy needs for separate water heating.

As with gains in refrigerator efficiency, the improvements in heat pumps and air conditioners will be the result of a variety of design and engineering changes. Larger heat exchangers with lower temperature gradients across them are being used. New refrigerant mixtures are being studied. More-efficient and reliable compressors are being developed. Variable-speed drives are receiving increased attention and are widely viewed to be the wave of the future.

In addition to making individual components better, researchers are looking to microprocessor-based controls to improve the interaction of the components. Refrigerant flow rates, for instance, could be regulated for peak efficiency, and variable-speed motors would reduce on-off cycling.

The gas industry is not taking these developments lying down. To improve on the traditional gas furnace with a seasonal efficiency of 60–65%, the industry developed a pulse combustion furnace that captures the energy released in the condensation of flue gas moisture to achieve efficiencies above 90%. First sold in 1982, condensing furnaces accounted for 12% of gas furnace sales by 1985.

The Gas Research Institute plans to go even further, however. By 1990 it hopes to commercialize the first-ever gas-fired residential heat pump, with an efficiency between two and three times that of today's conventional gas furnaces. GRI sees the commercialization of residential gas heat pumps as a key element in preserving natural gas's strong share of the space heating market and as a means of entering the air conditioning market.

However the market develops, the competition between electricity and gas is driving both kinds of technologies to ever higher efficiencies, with obvious benefits for consumers. The overall result will be that consumers in the early 1990s will be offered space conditioning equipment that is considerably more efficient than the best equipment available today.

Water heaters

The water heater is a much-maligned appliance, relegated to drafty closets and damp basements and thought of only in the blackest moments, when it fails and the shower turns icy cold in mid shampoo. Despite the fact that the water heater is one of the largest energy users in most homes, consumers frequently pay little attention to the efficiency of this appliance. They may wrap some insulation around the tank to hold back the heat loss, but when replacement time comes they often have the plumber install whatever unit is "on the truck," with little thought for efficiency.

For the more careful consumer, however, there are some efficiency options available in the water heating department. More-efficient versions of conventional gas and electric water heaters are on the market, with features like added tank insulation, lower pilot light settings, and heat traps that prevent convective heat flow out of the tank into the distribution line when hot water is not being used. These kinds of modifications have led to top-end models with efficiencies 15–20% higher than standard units.

Beyond these sorts of changes, however, there are several radically new water heater designs making their way into appliance showrooms. Electric heat pump water heaters have been developed with efficiencies twice that of conventional electric resistance water heaters. Their added cost will typically pay off in energy savings within 3–6 years. Because they remove heat from surrounding air, however, there is some concern that they will add to space heating requirements during the winter. To avoid this problem, Scandinavian homes commonly use heat pump water heaters that are coupled to mechanical ventilation systems. The heat pump draws heat out of the home's exhaust air, and the resulting hot water is used for both space heating and domestic use.

Integrated gas-fired units that heat water for both space heating and domestic use have also been developed. Because two functions are being served, features that would not be cost-effective in single-purpose units can be incorporated in an integrated appliance. The Polaris model manufactured by Mor-Flo Industries, Inc., for example, uses a high-efficiency gas water heater with electric ignition, sealed combustion, and flue gas condensation to provide water and space heating. Field tested in 1985–1986, the Polaris is due to be commercialized this year.

Cooking, cleaning, and drying

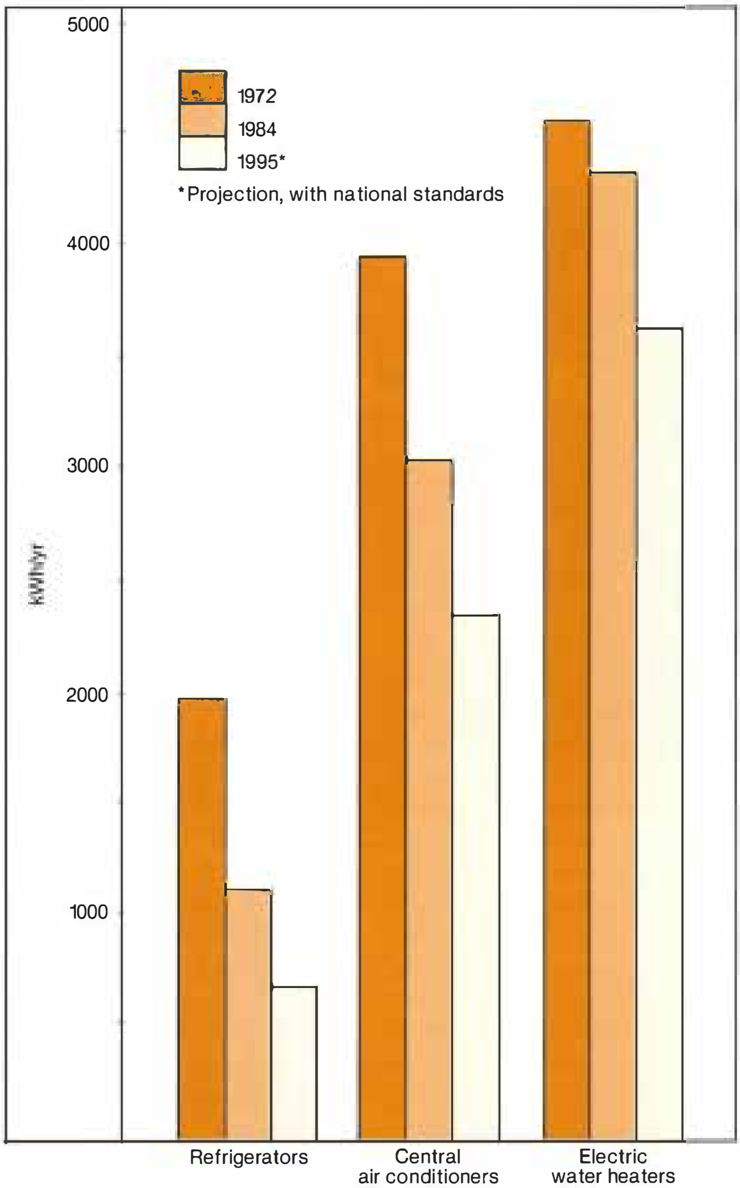
Just as Grandma would hardly have believed that the wood cookstove and wringer washer would give way to the automated cooking and laundry appliances of today, homemakers of the 1980s are in for some surprises of their own. Although conventional gas and electric ovens and cook tops have become somewhat more efficient in the last few years, the best models are about as good as this generation of equipment is going to get. The next quantum leap in efficiency will come with radically new designs.

A prototype biradiant electric oven with highly reflective walls and dual low-temperature heating elements uses two-thirds the energy of standard electric ovens. Microwave ovens, a standard fixture in many kitchens, reduce electricity demand 25–50%. Induction heating stove tops, which use a magnetic field to induce heat in the cooking vessel, are being marketed by several Japanese and American firms. These induction units offer greater control than do conventional electric stovetops because they heat only the cooking vessel and not the stovetop. They work with iron, steel, or copper cookware and cost considerably more but use 10–20% less electricity than standard electric designs.

In gas cooking equipment, the most energy-efficient design under development uses a ceramic flame holder to form jets of gas burning in holes in a glass plate. Known as the infrared jet-impingement burner, this design uses 50% less gas than conventional burners and produces less nitrogen-oxide pollution as a result of its lower combustion temper-

Charting the Efficiency Trend

Virtually all types of appliances are becoming more efficient, some faster than others. The changes to date have been driven by a combination of forces, including higher energy prices, competition between electricity and gas, and efficiency standards legislated in several states. If proposed national efficiency standards are enacted, there will be further significant increases in the efficiency of all major home appliances between 1990 and 1995. Some analysts estimate that the standards will reduce peak power demand in the year 2000 by 22 GW and save consumers up to $28 billion on their energy bills over the life of appliances purchased through the end of the century.



Source: Howard Geller, American Council for an Energy-Efficient Economy.

ature. The main problem with early prototypes was a poor turndown ratio (the ratio of maximum-to-minimum burner output), but the developers are working to resolve this. If the turndown ratio is improved, Caloric Corp. hopes to commercialize this design in some of its stoves in 1988.

Clothes washers and dishwashers used a third less energy in 1983 than in 1972, mostly by reducing their hot water demand. As up to 90% of their energy use is contained in the hot water that flows through them, this is the key to making these appliances more efficient. The most novel innovation in this area is a prototype jet spray dishwasher that has no motor but runs on water pressure from the faucet. Hart Industries of Laguna Hills, California, hopes to commercialize this product in 1987.

As with cooking equipment, conventional clothes dryers are reaching the practical and economic limits of their energy efficiency. Several innovative ways of getting the water out of the laundry are on the drawing board, however. Nyle Corp. of Bangor, Maine, has contracted with a Venezuelan firm to manufacture a closed-loop heat pump clothes dryer. According to Nyle's Donald Lewis, "Prototype tests show energy savings of up to 65% in comparison with conventional electric models. Because it will run on ordinary 110-V power and use a drain pipe rather than an exhaust vent to eliminate water recovered from the clothes, the heat pump clothes dryer may be particularly advantageous in apartment buildings." Nyle hopes to have this new product on the market in 1987.

Another novel approach, which General Electric Co. is looking at seriously, is the microwave clothes dryer. Several prototypes have been developed with reported 50% electricity savings. "Clothes dry faster and wear less in microwave dryers," says General Electric's Robert Reed. "We expect these machines to be commercially available within five years."

What it means for utilities

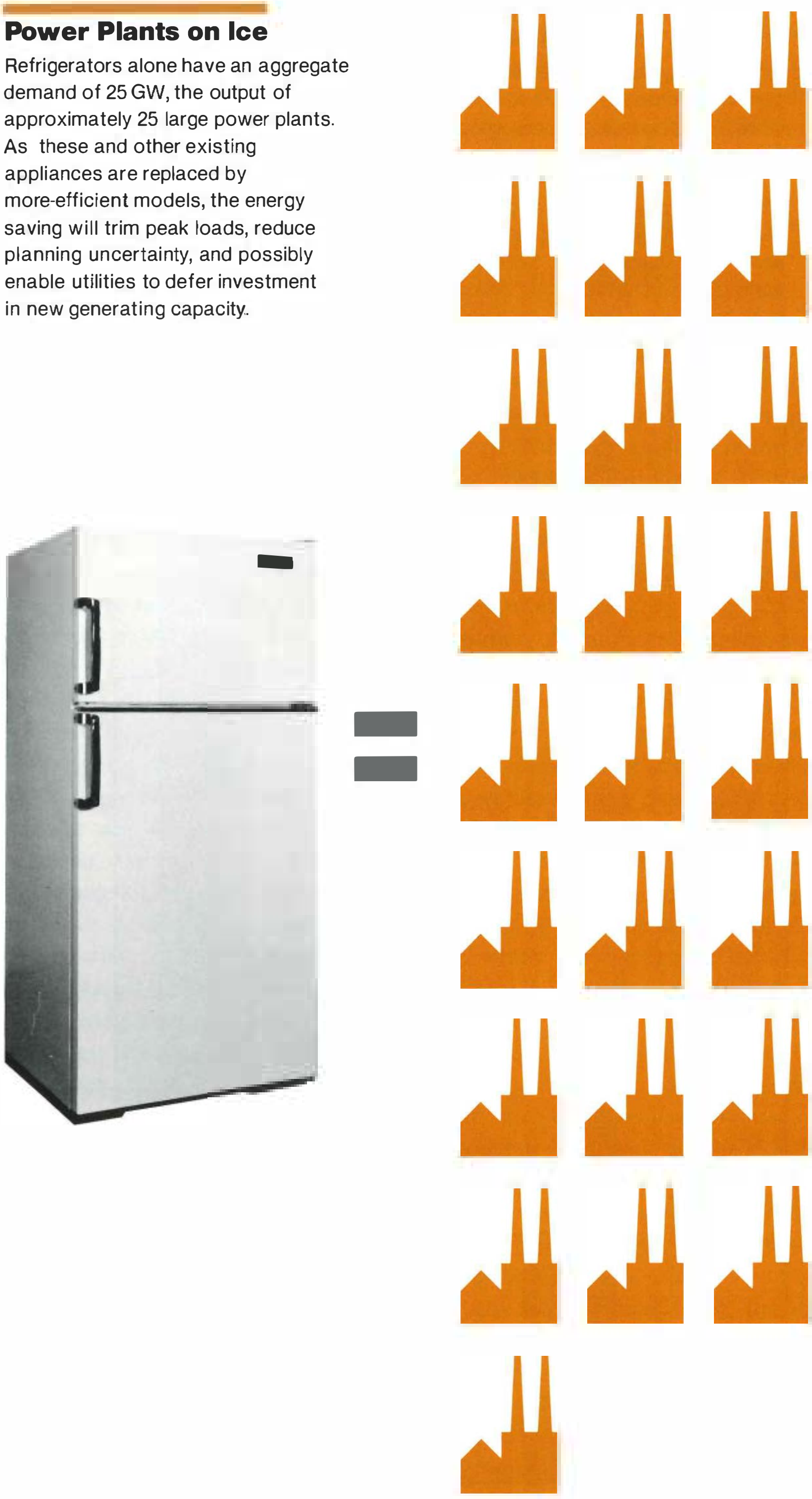
Although the details of efficiency gains in household equipment may seem unimportant when considered individually, viewed en masse they are very significant for utilities. More-efficient electric appliances can help maintain electricity's market share in such traditional strongholds as air conditioning and can attract new customers in areas like space heating that until recently have been dominated by gaseous fuels. A more-efficient appliance stock can trim peak loads and allow utilities to defer investment in expensive new generating capacity. Efficient appliances also reduce planning uncertainty by pulling down the upper range of load growth forecasts.

Many utilities have offered incentives, such as cash rebates, to encourage consumer purchase of high-efficiency appliances. A 1983 survey showed that such incentives were being made available to 60% of the households in the country. Most rebate programs have been targeted particularly at cooling equipment, with the aim of reducing summertime peak loads.

Texas Utilities Electric Co., for example, offers cash rebates of $40 to $75 per ton of reduced cooling load to residential customers who install new central air conditioning or heat pumps that meet certain minimum efficiency ratings. Rebates of $50 are offered for qualifying room units. According to Robert Morris of the utility's Conservation and Load Management Dept., "More than 400,000 customers have participated in the residential rebate program since it began in 1981. During the first three quarters of 1986, 83% of new single-family and 73% of new multifamily customers that installed central heating and cooling equipment participated." As of the end of September 1986, the rebate program and related load management efforts had trimmed 436 MW of residential load and another 247 MW of nonresidential demand, effectively deferring the need for a medium-size power plant.

Power Plants on Ice

Refrigerators alone have an aggregate demand of 25 GW, the output of approximately 25 large power plants. As these and other existing appliances are replaced by more-efficient models, the energy saving will trim peak loads, reduce planning uncertainty, and possibly enable utilities to defer investment in new generating capacity.



Texas Utilities Electric expects the rebates' success to continue. "We estimate that our 1987 program will achieve an additional 81-MW peak load reduction that will result in an annual electric bill saving of approximately $9 million for the 81,000 anticipated participants. Nonparticipating customers will also benefit by our programs through the delaying or eliminating of additional generating capacity," says Morris.

Not all appliance rebate programs are driven by an immediate need to reduce peak loads. Wisconsin Power & Light Co., for instance, has ample generating capacity but it is nevertheless running pilot studies of various appliance rebate approaches. Barbara McKellar, who coordinates WP&L's demand-side planning and program evaluation, explains, "We view the next few years as a window of opportunity in which to evaluate the delivery and customer acceptance of different incentive programs. At this point we are motivated by a desire to determine customers' needs and to explore cost-effective ways of meeting those needs. If and when the time comes that we need to trim our load, we'll have a mechanism in place to help us do so."

The great standards saga

Although appliance rebates and market forces have done much to encourage consumer investment in efficient appliances, one of the most potent forces driving further efficiency gains is government-mandated performance standards. According to Howard Geller of the American Council for an Energy-Efficient Economy, "standards help stimulate efficiency gains for certain products, like water heaters, where relatively little efficiency improvement has occurred in the marketplace, and for market segments, such as rental housing, where there are major barriers to conservation." The evolution of such standards has not been without controversy.

In 1978 Congress passed a law requiring that mandatory national efficiency standards be established for major home appliances. It took the government several years to develop the regulations, however, and when the Reagan Administration came into office it opposed standards on the grounds that they would interfere with the free market and that such matters should be left to the states. A series of lawsuits filed by environmental groups sought to force the Department of Energy to comply with the 1978 law. The courts ultimately ruled against DOE, ordering the agency to establish standards by 1988.

Meanwhile, California had passed its own standards in the late 1970s and added tighter regulations later to take effect in phases between 1987 and 1993. New York followed suit, and several other states began considering similar legislation. Wanting to avoid the dissection of their market into areas with different efficiency requirements, in 1986 appliance manufacturers joined an unlikely coalition of environmentalists, electric utilities, and regulators to support a consensus bill that would create uniform national standards. The bill passed Congress unanimously last October, but was pocket-vetoed by the president. The coalition reintroduced the legislation in January 1987. Given the broad bipartisan support the bill has enjoyed thus far, many observers expect it to become law this year.

The bill establishes energy efficiency standards for most major home appliances and for central heating and cooling systems, to take effect between 1988 and 1993. It supersedes further state regulation for a set period and bars revisions of the federal code or additional state regulations until specified dates. The standards are relatively stringent—70 to 90% of the appliance models produced in 1986 will not be permitted when the new rules take effect.

According to analysis performed by Geller, the standards would cut peak power demand in the year 2000 by 22,000 MW (the output of about 22 large power plants) and thereby avoid tens of billions of dollars in utility investment. Geller also calculates that the standards would offer consumers a net saving on their energy bills (after subtracting the added initial cost of more-efficient appliances) of $28 billion over the lifetime of appliances sold through 2000.

The Edison Electric Institute, which also supports the legislation, does not go as far as Geller in projecting savings, but nevertheless asserts, "This proposed legislation would provide a uniform base not only for appliance manufacturers and consumers but for utility planners as well. As less-efficient equipment is replaced, customers will be better able to meet their energy needs and manage their energy costs, while utility companies will benefit from reduced construction requirements for new plants. . . . The proposed legislation also would enhance the utilities' ability to anticipate future power demand."

Although they may disagree in their numerical forecasts of what national appliance standards will mean in terms of reduced peak demand, energy use, and planning uncertainty, all the bill's supporters agree that it would be an important step in the right direction. If the standards become law, the next generation of household appliances will be the most efficient in this nation's history. ■

Further reading

David Goldstein and Peter Miller. "Developing Cost Curves for Conserved Energy in New Refrigerators and Freezers." *Proceedings of the Summer Study on Energy Efficiency in Buildings.* Washington, D.C.: American Council for an Energy-Efficient Economy, August 1986, pp. 1.124–1.140.

Trends in the Energy Efficiency of Residential Electric Appliances. Final report for RP2034-9, prepared by Science Applications International Corp., April 1986. EPRI EM-4539.

Howard Geller. "Energy-Efficient Residential Appliances: Performance Issues and Policy Options." *IEEE Technology and Society Magazine*, Vol. 5, No. 1 (March 1986), pp. 4–10.

David Goldstein. "Refrigerator Reform: Guidelines for Energy Gluttons." *Technology Review*, Vol. 86, No. 2 (February/March 1983), pp. 36–46.

This article was written by Michael Shepard. Technical background information was provided by Howard Geller, American Council for an Energy-Efficient Economy; Robert Johnson, Whirlpool Corp.; David Goldstein, Natural Resources Defense Council; and Arnold Fickett, EPRI's Energy Management and Utilization Division.

TECH TRANSFER NEWS

Technology Ideas in Action

Successful technology transfer happens in lots of ways, and Pacific Gas and Electric Co. is a good example of a utility that uses many approaches and also tries new twists. PG&E uses the basics, of course—the Technical Interest Profile system to disseminate information on EPRI research products, an active technical information coordinator, staff attendance at EPRI workshops and seminars, and many individual memberships in the EPRI advisory structure.

Today, thanks to Thomas Jenckes, PG&E's technical information coordinator, the utility's newest twist on technology transfer is taking advantage of a 60-year-old employee incentive program. Already motivated by the long-established Ideas in Action program, many more eyes, ears, and minds at PG&E are now becoming alert to the cost-cutting potential of new technology from EPRI. With the appearance of a new information sheet on PG&E publication racks, the company does not have to depend solely on engineering or R&D staff members for ways to use new technology.

Jenckes, who is also a supervising engineer in the Engineering Research Dept., began with EPRI's *Ready Now* series of R&D results sheets. Organized by major categories of PG&E interest, such as nuclear plants and electric operations, these R&D products are now featured in the glossy single-sheet periodical called *Tech Transfer News.* Each issue briefly and simply describes about 10 products and gives each a reference number.

The new publication is distributed throughout the utility, and copies are displayed along with other EPRI and PG&E literature. Employees anywhere in the company's far-flung service territory can get more information by company mail or by using a toll-free telephone number. Requests are easily answered from background sheets that list EPRI source documents, names and telephone numbers of EPRI project managers, relevant references, and manufacturers' or marketers' names for products that are truly commercial.

Ideas in Action, the program to which Jenckes has hitched *Tech Transfer News*, is a long-running PG&E success story, always encouraging employee suggestions that either cut costs through improved operations or provide safety-related benefits. Employee awards range from $40 to $25,000, on the basis of their benefit to PG&E. In 1986, for example, the utility adopted 3417 suggestions, saving nearly $30 million. Awards totaled more than $2 million.

With its credibility firmly established, Ideas in Action seems made-to-order for companywide technology transfer. Moreover, the program staff monitors the flow of suggestions and gives special encouragement to company groups that are slow to contribute. Samuel Thomas, who heads the program, says it works well for three main reasons: management support from the very top, proven procedures that feature thorough review of all suggestions by utility people who would benefit from their adoption, and timely evaluation and feedback.

"Actually," says Thomas, "Ideas in Action needs support at every level if it is to thrive. Its success over such a long period is a tribute to management that consistently recognizes the value of employee contributions. The test is—it works."

Contacts: Thomas Jenckes and Samuel Thomas, Pacific Gas and Electric Co.; Pat Whittle, consultant.

Utility Guidelines for Solar Hot Water Systems

Utilities and their customers can turn to a new resource, *Solar Hot Water Manual for Electric Utilities* (EPRI EM-4965), to compare the economic benefits of domestic solar water heating systems with all the major electric options. The manual evaluates several demand-side alternatives for domestic water heating, with a particular focus on active solar systems. For utilities and their customers, the economic benefits of alternative water heating systems are contingent on geographic region and season of the year. Accordingly, the manual presents hourly load shapes for the various technologies by region and season.

The manual also contains generic comparisons of the various technologies, including conventional electric resistance, solar electric, load-managed solar electric, and heat pump. A section on customer education is also included. ■ *EPRI Contact: Gary Purcell (415) 855-2168*

Source Catalog for Demand-Side Planning

Demand-side management (DSM)—the planning and implementation of utility activities that influence customer electricity use—includes load management, the promotion of new uses for electricity, strategic conservation, innovative rate structures, and customer-generated electricity. A new publication, *The Demand-Side Management Information Directory* (EPRI EM-4326), compiles almost 2500 information sources into a single reference for utilities planning DSM activities.

The directory covers three areas: information needs, information sources, and linking sources and needs. Information needs fall into nine categories: setting objectives, selecting technology alternatives, assessing customer acceptance, evaluating customer response, estimating load shape effects, identifying transmission and distribution system impacts, conducting cost-benefit analyses, implementing DSM programs, and monitoring program progress. Information sources include utility contacts, planning models, metering studies, utility surveys, reports, handbooks, and demonstration projects. Listings in the directory review the range of information available from each of these sources.

In addition, the directory contains cross-references and case study presentations that link specific sources with individual information requirements. For example, a matrix on residential DSM technologies lists sources of information on performance characteristics, installed costs, customer preferences, and energy savings under the categories of building insulation, passive solar equipment, heat pumps, and load control systems. The publication is available from the Research Reports Center. ■ *EPRI Contact: William M. Smith (415) 855-2415*

Guidelines for Fly Ash Utilization Programs

Utilities can now use *High-Volume Fly Ash Utilization Guidelines* (EPRI CS-4763) to achieve success in promoting the use of large volumes of fly ash for construction, landfill, and other applications. These guidelines are designed to help utility managers evaluate a range of options to structure programs suited to their particular market situations.

The guidelines address and evaluate all major constraints on high-volume fly ash utilization. In addition to discussing the technical issues for each application, they examine the constraining issues of utility commitment to utilization and of public acceptance, economics, liability, and competition. They also offer action plans for individual utilities to consider in resolving their marketing constraints.

Utilities can use these guidelines to evaluate existing marketing programs and to identify the major roadblocks to increasing utilization. On the other hand, utilities that do not already have high-volume ash utilization programs can use the guidelines to gauge which constraints deserve their concentrated efforts. ■ *EPRI Contact: Dean Golden (415) 855-2516*

Methods for Determining Past Acidity of Lakes

To fully understand lake acidification, policymakers must analyze changes that have occurred over the past two centuries in the pH levels of lakes assumed to be vulnerable today to acidification from atmospheric deposition. To aid in this task of determining past conditions, utilities and other organizations can use the protocols and design criteria contained in *Paleoecological Investigation of Recent Lake Acidification: Methods and Project Description* (EPRI EA-4906).

In this approach, past pH profiles are inferred by analyzing the remains of two kinds of microorganisms, diatoms and chrysophyta, that are found in sediment at the bottom of lakes. Measurements of lead-210, pollen, and charcoal are used to date the sedimentary strata. The approach can be used to study past and present changes in the pH of lakes and to evaluate changes that may occur in the future. ■ *EPRI Contact: Robert Goldstein (415) 855-2411*

NDE Guidelines, Software for Boiler Tubes

Boiler tube failures are the primary cause of forced outages in U.S. fossil fuel plants, responsible for approximately 6% of all availability loss. To detect damage in tubes and prevent failures, utilities are making increased use of ultrasonic testing and other nondestructive testing methods for boiler inspection.

For planning and conducting this type of boiler tube inspection with maximum effectiveness and efficiency, utilities can refer to *Fossil-[Fuel]-Fired Boiler Tube Inspection, Vol. 1: Nondestructive Testing Guidelines* (EPRI CS-4633). They can also use the guidelines in combination with two microcomputer software programs that were designed in the same project.

This first volume of guidelines extends from the planning of an inspection program to postinspection analysis of data. The guidelines describe nondestructive testing methods for assessing wall thickness, cracking, pitting, and hydrogen damage. Also included are procedures for determining equipment and labor resources and for soliciting proposals from contractors. Additional sections outline methods for preparing tube surfaces, qualifications for inspection personnel, and estimated inspection costs.

The computer programs are used to map tube failure location and cause, store and display inspection data, predict optimal inspection intervals, and estimate when tubing should be repaired or replaced. The software, consisting of a boiler economic analysis program (BEAP) and a boiler tube status (BOTS) program, is discussed briefly in Volume 1 of the guidelines. Volume 2 of the guidelines, available in mid 1987, will describe the programs and their use in more detail. Both the software and the guidelines are designed to supplement EPRI CS-3945, which describes tube failure types and a program for identifying and treating their root causes. ■ *EPRI Contact: John Scheibel (415) 855-2850*

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Vice President

MAINTAINABILITY ANALYSES WITH UNIRAM

The UNIRAM model and method were developed to provide a means for assessing the availability of proposed electric power generating units. The model is general in structure and can be applied to a variety of generation schemes. In a recent study, UNIRAM was used to analyze the maintenance characteristics of a coal pulverizer subsystem.

One of the principal inputs to the UNIRAM model is the mean downtime (MDT) of the subsystems, components, or basic parts entering into the evaluation of system availability. The manner in which MDT is used makes it possible to evaluate and possibly optimize maintenance policies relating to spare parts inventories and manpower because MDT is influenced by both labor and material logistics.

A coal pulverizer subsystem was analyzed to evaluate the usefulness of the UNIRAM method (RP1461). The pulverizer subsystem is a part of the Brandon Shores No. 1 unit, a 500-MW coal-fired unit in baseload operation since 1984 for the Baltimore Gas & Electric Co. It consists of five pulverizer mills, each of which provides 22.5% of the total plant output. Although this particular subsystem was chosen for analysis by BG&E, any unit, subsystem, or component could have been accommodated because the UNIRAM method was designed to be applicable to a variety of systems.

In this study, UNIRAM was used to determine the equivalent availability of the generation unit, given various combinations of pulverizer spare parts and maintenance policies. The support options comprised 4 spare parts levels and 5 maintenance policies, or a total of 20 different combinations of the two.

The four spare parts options were as follows: option 1, no spares; option 2, three spare wheel assemblies; option 3, three spare wheel assemblies, a set of track segments, and a classifier cone; and option 4, the same as option 3 with an added gearbox and driver. The five maintenance policies were (1) single shift, 5 days; (2) single shift, plus 2 hours overtime; (3) double shift; (4) triple shift; and (5) labor as required.

MDT is constructed out of the elements of logistics time (which may be taken as zero if the parts are in inventory, or as the time required to obtain them after failure) and elapsed time (which is determined by the number of man-hours required, crew size, and number of shifts). Given the different MDTs for each combination of spare parts and maintenance policy, the UNIRAM model determines the corresponding equivalent availability.

The results are used to assist in rating the 20 combinations, allowing comparison of the productivity improvement or degradation on a case-by-case basis. The value of the difference can then be associated with the cost in terms of spare parts, procurement delays, and maintenance policy; the preferred combination can then be selected.

The quality of the analysis depends very much on the accuracy of the inputs for procurement delays and labor time. If these are not available, which may be the case if new equipment is being used or if records are scant, data have to be developed through expert judgment or through some form of failure mode analysis.

Exercising the UNIRAM model for the 20 combinations of spares and maintenance policies produced a new set of equivalent availability results. As expected, equivalent availability improves as more spare parts are kept in inventory. Less expected, and perhaps contrary to what would be expected intuitively, is the magnitude of the differences encountered (which can be smaller than presumed) and their value.

These differences in equivalent availability are shown in Table 1, where they are converted to annual output expressed as an increase in production (in MWh) above that available for the no-spares and single-shift option. The production increases range from 2190 MWh for the overtime shifts and no spares to a high of 23,602 MWh for the combination of a triple shift and spares option 4. The table shows a significant production increase (relative to the no-spares option) for the option of three spare

Table 1
ANNUAL OUPUT INCREASES FOR STUDY SPARES AND MAINTENANCE OPTIONS

	Output Increase (MWh) by Spares Option*			
Maintenance Policy	Option 1	Option 2	Option 3	Option 4
Single shift plus overtime	2,190	15,768	20,586	23,214
Double shift	2,190	14,454	19,272	21,900
Triple shift	1,752	14,016	18,396	23,652
Labor as required	1,752	12,702	15,330	21,462

*The increases shown are relative to the single-shift, no-spares option and are attributable to improved labor availability.

Table 2
ANNUAL OUPUT INCREASES ATTRIBUTABLE TO SPARES INVENTORY

Maintenance Policy	Output Increase (MWh) by Spares Option*		
	Option 2	Option 3	Option 4
Single shift	152,000	191,000	261,000
Single shift plus overtime	152,000	191,000	260,000
Double shift	150,000	189,000	257,000
Triple shift	150,000	189,000	257,000
Labor as required	150,000	191,000	258,000

*The increases shown are relative to the no-spares option and are attributable to improved parts availability.

wheel assemblies, but less significant changes for stocking the other items.

Similarly, Table 2 shows the annual production differences that are attributable to changes in the spare parts inventory; that is, the difference between having a given spare parts option and not having it.

In all these cases, the value of the changes in production can be compared with the cost of achieving those changes—that is, the cost of carrying a spare parts inventory and costs of multiple or overtime shifts. It is evident from Table 2 that in the case being analyzed there is no advantage in using more than a single shift; actually, it is more costly to make the fastest repair (i.e., to use labor as required).

The results in neither table address the basic question of the economics of making any change, but they do provide the basis for doing so.

It is possible to make a sample calculation of benefits and costs by making several assumptions and examining the results. Assuming a 5-man shift that costs $35 per man-hour regular time and $52.50 per overtime hour (in each case, including supervision, overhead, and all benefits), the annual cost for a 10-hour day is $481,000. The additional output of 15,768 MWh is assumed to be valued at $50/MWh for a total of $788,400, which is a significant advantage. This is only a crude approximation to a minimum benefit because the crew may be expected to be making other repairs during the same annual period (or, on the other hand, not working overtime at other times).

The relationship between spares inventory, maintenance policies, and system design is a complex one and does not always lend itself to ready evaluation and optimization. The maintenance and productivity aspects of the UNIRAM method provide an easy way to quantify the cost-related aspects of these characteristics and to combine them with other economic inputs to arrive at desirable benefit-to-cost policies. *Project Manager: Jerome Weiss*

PROTECTIVE COATINGS AND CLADDING FOR TURBINE BLADES AND VANES

Many utilities operating gas turbines have had to replace or repair turbine blades and vanes at excessive cost as a result of hot corrosion. A number of EPRI projects have helped identify the causes of this rapid deterioration, as well as identify control strategies and protective coatings to reduce its effect. A variety of coatings are now commercially available, and utilities should know which are best for their particular needs. The focus of EPRI's present work is to encourage field-testing of commercially available coatings in a number of applications and to document the results. The product of this effort will be an applications guide for the selection of coatings based on users' individual environments, fuel choices, and duty cycles.

In the early 1970s the gas turbines of many utilities suffered severe blade and vane corrosion that rarely affected older units. The new turbines, designed for improved efficiency and increased power output, operated at higher temperatures. The blade and vane materials were resistant to high-temperature oxidation but not to the newly recognized low-temperature corrosion that occurs in the 1100–1400°F (590–760°C) range. Although more-corrosion-resistant materials have been developed, turbines need additional protection in the form of coatings or cladding.

Initial research identified low-temperature corrosion, developed an understanding of its formation, and devised ways to control it. At the same time, considerable effort went into formulating and testing new coatings for base metals. In laboratory burner tests under controlled conditions, researchers tested and screened the new coatings. However, as utilities began to use them, these coatings did not always perform as predicted. It became obvious that the site-specific environment, fuel quality, and turbine duty cycle differed from the standard laboratory screening tests. Results of actual field tests were needed to guide utilities in selecting proper coatings for their particular applications. These field tests would have to be carried out under the variety of environmental, fuel, and load cycle conditions normally encountered.

EPRI developed a plan to gather information and results on any field tests completed or in progress and to promote new tests for applications not currently quantified. The EPRI study considers only those coatings that are commercially available—coatings that have been developed over the past 10 years, as well as coatings that have been used in aircraft engines for the past 20 years.

The project series consists of the following steps.

- Research the commercially available coatings and their general service application
- Formulate a matrix of test conditions representative of the various types of utility operation
- Promote field tests and evaluate results to determine the most suitable coatings for each set of operating conditions
- Disseminate test results, provide a reference book of available coatings, and provide an applications guidebook based on actual field performance evaluations

Field tests

Southwest Research Institute is preparing the matrix of test conditions that will help establish meaningful field tests and select the coatings to be tested at each site (RP2388-3). The contractor will also develop a reference book of commercially available coatings and suitable applications, as well as document the results of the various field tests and prepare a final guidebook for coating selection. Also under RP2388-3, Southwest Research evaluated a field test conducted by Long Island Lighting Co. (Lilco) on Turbo Power & Marine Systems' FT4 engine. The engine operated for 800 hours in peaking service on No. 2 fuel oil at a site that historically produced a high corrosion attack on first-stage vanes.

In other projects Solar Turbines, Inc., researched commercially available coatings for the most suitable candidates for a rainbow test on first-stage nozzles and blades of a Centaur T-4000 engine that would operate at baseload on No. 2 fuel oil at a historically corrosive site. (A rainbow test is one in which many coatings are applied to a single stage to determine their protective characteristics.) Parts were coated and the engine fired for 8000 hours (RP2388-1, RP2465).

Southwest Research has completed the cataloging of commercially available coatings and general applications and has collected information on quality control, refurbishment, and effects on superalloy mechanical properties. A report will be available in early 1987. In addition to listing commercially available coatings, the report will discuss types of coatings and techniques for applying them. It will also summarize field tests and discuss future coatings research. The test matrix will be completed shortly, and EPRI will use it to plan and direct future field tests.

The only field test currently being monitored is on a Solar Turbines machine (RP2465). The first engine with coated vanes and blades was placed in service in July 1984 at the Owens-Corning Favianca glass plant at Valera, Venezuela. When the engine had operated for 8000 hours, it was returned to Solar Turbines' San Diego repair shop. The vanes and blades were examined for hot-corrosion damage, and coating performance was evaluated by comparing the as-received and the as-coated blades and vanes. The test was terminated at 8000 hours because an unrelated engine failure severely damaged the first-stage blades. Because this site operates at baseload on fuel oil and has a historical corrosion problem, a second coated engine was placed in service in May 1986 and has been operating at baseload since then. This second test will confirm data and provide new data on first-stage blade performance.

Test results

Although the number of field tests available at this time is limited, some general guides can be developed for selecting coatings for specific applications. Further testing is needed to confirm some of these early results. AP-4194 documents the evaluation and findings at the Long Island field test after 812 hours. The report ranks the test coatings. Results show that none of the coatings is totally corrosion-resistant because even the best coatings still allowed small localized areas to be completely penetrated. Table 3 ranks coatings only on the basis of their corrosion resistance. Although the coatings had been ranked from best to worst, there was little difference between the CoCrAlY (cobalt-chromium-aluminum-yttrium) and the platinum-rhodium-aluminide, or between the two rhodium-aluminide coatings.

Table 3
RELATIVE CORROSION RESISTANCE OF COATINGS
(decreasing order)

Coating	Designation
Cobalt-chromium-aluminum-yttrium (HIP)	IM6250
Platinum-rhodium-aluminide	RT44
Rhodium-aluminide (HIP)	IM6255 (BB)
Rhodium-aluminide	IM6255 (BB)
High-pressure plasma spray and ceramic	PWA45 and ceramic
Basic aluminide	PWA45
Aluminide (HIP)	PWA45
Low-pressure plasma spray and ceramic	PWA45 and ceramic
Palladium-aluminide	PWA27 and RT100

Also at the bottom of the scale, there was little difference between the palladium-aluminide, the hot isostatically pressed (HIP) basic aluminide, and the low-pressure plasma spray and ceramic coatings.

The rankings shown in Table 3 also require some qualification. Choice of the CoCrAlY coating as the best is based solely on its excellent corrosion resistance. However, three of the CoCrAlY vanes had to be replaced after 655 hours of operation because of large thermal fatigue cracks on their concave surfaces. Therefore, if a coating is being chosen for its total integrity, both corrosion resistance and fatigue resistance, then the CoCrAlY coating would be excluded and the platinum-rhodium-aluminide coating would be the best choice. If the CoCrAlY coating is excluded, the precious-metal aluminides offer the best protection, with the exception of the experimental palladium-aluminide coating, which performed poorly. The high-pressure plasma spray and ceramic coating has an intermediate ranking because its underlying aluminide coating remained protective, even though much of the overlying ceramic layer had been removed.

EPRI has also sponsored a study to optimize the composition of MCrAlY (metal-Cr-Al-Y) coatings to protect against both type 1 and type 2 hot corrosion. Laboratory tests show that the best coatings were Co-35Cr-8Al-0.5Y and Ni-20Co-35Cr-8Al-0.5Y. These coatings were applied to MAR M-509 vanes and tested in an FT4 engine, using No. 2 distillate fuel, at Pacific Gas and Electric Co.'s (PG&E's) Oakland, California, station. Vanes coated with a Co-22Cr-12Al-0.5Y commercial coating were also tested. After about 750 hours of cyclic duty, most of the vanes coated with both types of CoCrAlY were found to contain cracks. This experience reinforces the findings of the Lilco study (AP-4194) and indicates a general vulnerability of the CoCrAlY-type coating to thermal fatigue under cyclic operation.

Evaluation of the Venezuela tests, which will be reported in early 1987, supports some of the findings of the Lilco and PG&E tests. The Solar Turbines' report indicates MCrAlX (X = Y and/or Hf) overlay coatings generally outperformed simple and modified aluminides on both first-stage turbine blades and vanes. Both chromium- and platinum-modified aluminides displayed severe degradation on the platforms of IN 738LC, IN 792, and MAR M-421 first-stage turbine blades in a temperature regime generally associated with type 2 hot corrosion (~1100–1200°F, 590–650°C), whereas overlay coatings, apart from minor cracking, remained intact.

The chromium-modified aluminide coating (MDC-9) appears to afford better hot-corrosion protection than the simple (H9 109) and platinum-rhodium–modified (RT44) aluminide on the FSX414 and MAR M-509 vanes. Because there was no noticeable difference between chromium-modified (RB 505) and platinum-modified aluminide (RT 22A and LDC 2E) coatings on the blade platforms, it is possible that the higher temperature of the vane airfoils (1400°F, 760°C) compared with that of the blade platforms (~1100–1200°F, 590–650°C) is of importance in this respect.

Future efforts

The next major project, and probably the most difficult, will be to implement future testing in accordance with the test matrix being developed. The test plan will include sites with clean and contaminated air-, gas-, or oil-fired units, peaking or baseload operation, and various base metal turbine parts. The variations are numerous, but the primary effort will be to test in those conditions that are applicable to the majority of utilities whose turbines currently suffer the effects of hot corrosion.

Once the selected conditions are established, EPRI will solicit host sites. Some problems in site selection are the cost of removing and coating the test parts and collecting data on air, fuel, and duty cycle. In baseload applications the installation of test components may be delayed for a year or more to coincide with a planned overhaul outage.

The goal of producing a comprehensive guidebook summarizing field test experience may be a long-term one because of the time needed to select test sites, accumulate data over hours of operation, and evaluate and compile the data. *Project Manager: Charles Knauf*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

CHARACTERIZING FUELS FOR AFBC

Experience with conventional pulverized-coal (PC) power plants has shown that a thorough knowledge of fuel characteristics is essential to efficient boiler design and operation. The failure to fully understand these characteristics can have serious and expensive consequences. One utility, for example, was forced to operate a lignite-burning plant well below its rated capacity for several years because of slagging problems and eventually had to build a supplemental boiler. Although atmospheric fluidized-bed combustion (AFBC) boilers are considerably more flexible than their PC counterparts, this new technology likewise requires detailed fuel characterization for proper boiler and balance-of-plant design. An inadequate knowledge of the fuel or fuels to be used in an AFBC plant could lead to derating and retard the commercialization of AFBC for utility applications. To help plant designers get the data they need, EPRI is sponsoring work to develop an AFBC fuel characterization method (RP718-2).

The data base and methods of characterizing coal that have been developed over the years for PC boilers are not adequate for the design of AFBC boilers. There are significant differences between the technologies—for example, combustion temperature, particle heating rate, and feedstock particle size—that cause the same coal to behave differently in the two types of unit. Thus, as commercial AFBC units at utility scale become reality, designers are faced with the problem of getting the required knowledge of fuels in a relatively short time.

Perhaps the surest way of characterizing fuels for AFBC is to test them in an actual fluidized-bed boiler. The TVA–EPRI 20-MW (e) pilot plant is a potential site for such tests, but at approximately $1 million per fuel tested, the cost for even a few tests is prohibitive. Boiler vendors now use small test rigs or laboratory analyses in preparing bid packages with performance guarantees. Because these test methods are usually proprietary, however, and have not yet been proved by large-scale system performance, utilities cannot be certain about the validity of the guarantees for this relatively new technology. In light of this situation, EPRI initiated a project to develop a cost-effective method of characterizing fuels for commercial-scale AFBC units.

The project approach is to use small-scale tests together with a performance prediction code that will serve as the scaling link to commercial units. Investigators at Babcock & Wilcox Co.'s Alliance Research Center in Ohio—with guidance from representatives of other boiler vendors—are identifying tests to take the place of large-scale AFBC test burns in providing design data. They are also developing the necessary bench-scale test rigs and the performance code. The goal is to develop tests that will become standards for the industry, similar to the standard ASTM tests for PC design.

Naturally, the researchers looked first at the tests PC designers rely on, such as the standard ash fusion temperature test, which characterizes a coal's ash behavior and slagging tendencies. This test is not useful to AFBC boiler designers, however; because temperatures in an AFBC combustor do not reach the fusion temperature of most coals, slagging is not a problem. In terms of fuel ash, the only concern of AFBC designers is to determine the place the ash will end up in the system, where it will have to be dealt with as a solid waste. Ash can travel to the back-end particulate cleanup equipment (as small particles) or remain in the fluidized bed (as large particles) and eventually drain out with other inert wastes.

Another test used by PC designers is the Hardgrove grindability test, which establishes a coal's grinding characteristics so that the correct pulverizing equipment can be selected. This test, too, appears to have little direct relevance for AFBC units, which burn crushed rather than pulverized coal. The project team has found, however, that an important factor in determining combustion efficiency for a fluidized-bed boiler is the particle size distribution of the coal. Both the crusher and the feed system affect size distribution. If these systems produce excessive fines, combustion efficiency may be reduced because the fines may blow out of the fluidized bed (elutriate) without burning. Different coals break up differently under the same mechanical forces, and an AFBC designer must know how the design coal and alternative fuels will behave in the system before reaching the boiler. The project team has developed a simple feed line attrition test to provide data on feed size distribution for use in the performance code. The test involves a batch run through the feed line of a cold test rig, which is equipped with a bag over the coal injector to catch the exiting test sample. The collected sample is then sieved and its size distribution compared with the original distribution. With enough data, it may be possible to correlate the feed line test results with those from the Hardgrove grindability test or another existing standard test.

The review of PC fuel characterization tests confirmed the need for new or revised tests that take account of the differences in operating conditions between AFBC and PC units. The temperature and particle heating rate are much lower in an AFBC boiler and the average coal particle size is much larger. Further, the action in a fluidized bed is very different from that in a conventional PC boiler. Coal particles entering a fluidized bed encounter a dense mix of particles of calcined, sulfated, and fresh limestone, all close to the same temperature and all roiling and chafing at a fast rate.

With the special conditions of fluidized-bed combustion in mind, two test rigs have been built and tested at the Alliance Research Center. One, a fixed-bed reactor with a 3-in (7.6-cm) diameter, is capable of operating at various temperatures, oxygen concentrations, and coal-feed particle sizes. It was designed to determine a coal's chemical characteristics (e.g., devolatilization and char reactivity) under fluidized-bed combustion conditions. The other rig is a fluidized-bed reactor with a 6-in (15.2-cm) diameter. It can operate at various temperatures, gas velocities, and particle sizes to determine a coal's physical properties (e.g., attrition) under fluidized-bed combustion conditions.

To date, the primary objective of testing in these new rigs has been to obtain the information necessary for estimating the amount of combustion that occurs in the dense bed of a bubbling-bed AFBC reactor. In-bed combustion is one of the major determinants of overall combustion efficiency in this type of AFBC boiler because the dense bed is the most favorable environment for combustion. (The fuel characteristics being identified in these tests are also important with respect to the circulating-bed type of AFBC boiler, where they influence the patterns of heat release along the furnace height.) As testing continues, the researchers will investigate above-bed combustion and fly ash recycling in bubbling-bed boilers; other aspects of circulating beds will be studied as well.

Devolatilization is one of the mechanisms being investigated that affect in-bed combustion. As a coal particle heats up, the volatiles are released first; thus they tend to contribute more to in-bed than to above-bed combustion. It is important to find out how much volatile matter is released (the volatile yield) and at what rate it is released (the devolatilization rate). The fixed-bed reactor is used to obtain these data.

The devolatilization testing provides a measure of carbon dioxide (CO_2) release—and hence, indirectly, of combustibles—as a function of time. The coal is burned in the fixed-bed reactor, and then the off-gas is passed through an afterburner to complete the reactions to CO_2. The CO_2 is measured with a continuous analyzer and shown in real time on a strip chart recorder. Figure 1 presents results from a test with constant temperature, particle size, and oxygen concentration. The sharp rise of CO_2 at the start indicates the volatile release; the point at which the release of CO_2 decreases indicates where devolatilization stops and char combustion begins. The area under the upward curve is considered the volatile yield. The slope of the curve indicates the devolatilization rate.

Char reactivity is another important factor that must be considered in predicting in-bed combustion. This is the rate at which char, the carbon material left after the volatiles have been released, burns. Reactive char—that is, char that burns quickly—will tend to increase in-bed combustion. The CO_2 time history taken in the fixed-bed reactor can also be used to determine char reactivity.

The chafing of particles in a fluidized bed causes bits of particles to break off. This process of attrition occurs under cold conditions, as the feed line tests described above have shown. In addition, the project team has found that attrition may increase under hot conditions. Some of the particles created by this combustion-enhanced mechanical attrition (CEMA) will be small enough to immediately elutriate from the bed. The more the coal breaks, the greater the amount of carbon that elutriates; thus in-bed combustion is reduced, and overall combustion efficiency may drop.

The two coals tested so far, Pittsburgh No. 8 and Kentucky No. 9, indicate that CEMA can indeed have an effect on overall combustion efficiency. These bituminous coals are similar in their ultimate and proximate analyses, but they behave differently in a fluidized bed. Pittsburgh No. 8 has a higher ratio of volatile matter to fixed carbon, which suggests greater reactivity. In tests run in a small-scale (1-ft × 1-ft) AFBC unit at the Alliance Research Center, however, combustion efficiency was lower with the Pittsburgh coal than with the Kentucky coal. Figure 2 shows the combustion efficiency for the two coals as a function of the ratio of recycled fly ash to coal feed. With both coals the efficiency rose as the amount of fly ash recycled was increased, but it was consistently higher with Kentucky No. 9.

The cause of these differences in combustion efficiency is the difference in the extent to which CEMA affects the two coals. According to tests in the 6-in fluidized-bed reactor, the CEMA rate constant for Pittsburgh No. 8 was about three times that for Kentucky No. 9. The higher CEMA for Pittsburgh No. 8 causes more carbon to elutriate from the bed, which suggests a lower overall combustion efficiency. An examination of coal fines from the CEMA tests found the Pittsburgh No. 8 sample to contain considerably more carbon than the Kentucky No. 9 sample. These early tests show that CEMA is another important factor in in-bed combustion and hence must be evaluated in AFBC fuel characterization.

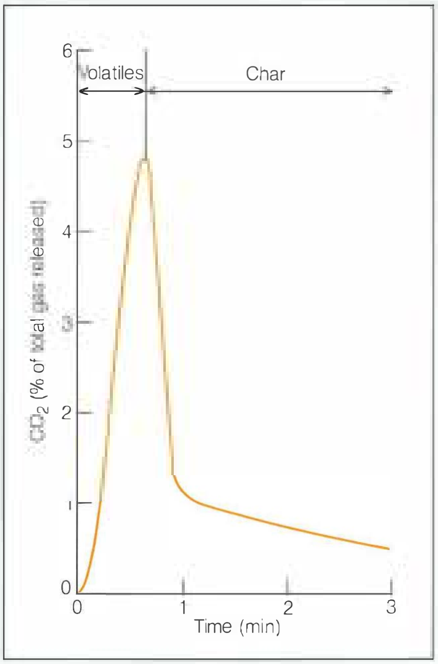
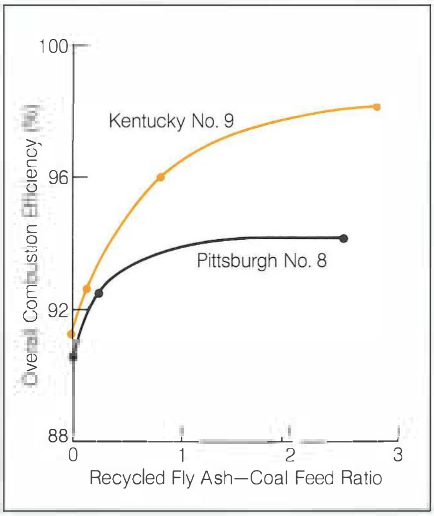


Figure 1 CO_2 release during coal combustion in a bench-scale fixed-bed AFBC reactor. From this time history researchers can determine the coal's volatile yield, devolatilization rate, and char reactivity—information needed to estimate heat release patterns and combustion efficiency for AFBC boilers.

Figure 2 Combustion efficiency as a function of the ratio of recycled fly ash to coal feed was determined for two similar bituminous coals in a 1-ft × 1-ft AFBC test rig. Later bench-scale tests suggest that the differences in efficiency are due to the Pittsburgh coal's greater susceptibility to combustion-enhanced mechanical attrition.



The bench-scale tests being conducted in RP718-2 are paving the way toward more-accurate and less-expensive fuel characterization for AFBC boiler design. At the current rate of progress, utilities and designers can expect to have the necessary techniques and a representative data base by 1990. *Project Manager: Ellen M. Petrill*

FABRIC SELECTION FOR BAGHOUSES

As part of its R&D on fabric filtration, EPRI has undertaken a systematic study of how fabric and filter bag characteristics affect baghouse performance and bag life (RP1129). Specialized equipment is being used that permits the monitoring of individual bags within a baghouse compartment and thus substantially reduces the time required to test a comprehensive range of fabrics. The test program, conducted at EPRI's Arapahoe Test Facility in Denver by Southern Research Institute and Electric Power Technologies, Inc., is guided by an advisory group from the filter bag industry (glassmakers, fabric weavers and finishers, and bag vendors). Results from the first 1000 hours of testing are now available. It is expected that the test data will lead to improved *fabrics and filter bags and will enable baghouse operators to select the fabrics and bags best suited to their particular site and coal.*

Fabric and filter bag characteristics are known to affect baghouse performance and operating costs. Although the relationships between fabrics and fly ash dustcakes are not well understood, different fabrics do result in residual dustcakes that differ in terms of drag (resistance to gas flow) and weight; these in turn affect baghouse pressure drop, bag life, and in some cases particulate matter collection efficiency. Baghouse performance, it is generally believed, would be improved if filter bag specifications could be tailored to utility applications and even to particular coals.

In practice, the selection of filter bags is typically based on recommendations from vendors or on operator experience. Evaluations of test bags for limited trial periods are sometimes conducted by dedicating single compartments of a commercial baghouse to different fabrics and then monitoring performance. The results, however, are difficult to generalize to other sites or coals. Further, because filter bags require several thousand hours of operation to reach quasi-equilibrium conditions with respect to dustcake formation and because there are numerous fabric, finish, and bag variables, it would take years to conduct a comprehensive program to optimize bag design.

The RP1129 project team has developed an alternative approach that uses EPRI's fabric filter pilot plants. This approach assumes that performance tests of different filter bags in the same baghouse compartment will produce valid comparative information, provided that only one fabric design parameter is varied per compartment. A necessary adjunct to this approach is an innovative capability to monitor the operating and performance characteristics of individual filter bags in a compartment; with that capability, researchers can use a fabric filter pilot plant to obtain directly comparable information on dozens of different filter bags within a period of months.

The EPRI test program is taking this approach to identify and quantify the effects on baghouse performance of four fabric design parameters: yarn construction, texturization, weave, and finish. The program's novel experimental features and its preliminary results are discussed below. An essential element of the program was the formation of a manufacturers' advisory group of representatives from the filter bag industry. The group supports EPRI's fabric research by participating in the formulation of experimental test plans; the specification, procurement, and fabrication of test bags; the preliminary review of relevant technical publications; and the interpretation and dissemination of research results.

Fabric filter pilot plant

EPRI is conducting the fabric research in the 2.5-MW (e) baghouse at the Arapahoe Test Facility. This pilot-scale baghouse has four compartments and accommodates a total of 144 filter bags, each about 8 in (20 cm) in diameter and 22 ft (7 m) in length. In each compartment bags are arranged in a 6×6 matrix. Bag cleaning can be by reverse gas or by the shake/deflate method. The facility operates on low-sulfur subbituminous coal, and the test results are considered applicable primarily to plants using that type of coal.

The pilot baghouse was modified in order to install an individual bag flow monitor (IBFM) system. Manufactured by ETS, Inc., this system permits on-line monitoring of the rate of flue gas flow through each filter bag (and hence the air-to-cloth ratio for each bag). The IBFM system consists of 144 flow rate sensors (installed atop the tubesheet thimbles), two signal-conditioning modules, two control and monitoring modules, and a data reduction computer. The system can monitor and store data for any 36 of the flow sensors at one time; thus, to develop historical data relationships for all 144 filter bags, it is necessary to survey the filter bags sequentially in a time-sharing arrangement. Installation was completed in mid 1986, and the IBFM system is successfully being used in the current test program.

Preliminary tests of fabric texturization

In 1985, before the IBFM system was installed, the pilot baghouse was used to study the effect of fabric texturization. For that experiment each of the four compartments contained identical bags, with the degree of exposed texturization on the filtering side of the bags varying among the compartments (0, 25, 75, and 100% exposed texturization). The degree of exposed texturization depends on the type of yarns used in the warp (lengthwise) and fill (crosswise) directions, the weave pattern, and the fabric orientation.

Figure 3 presents the results after 7000

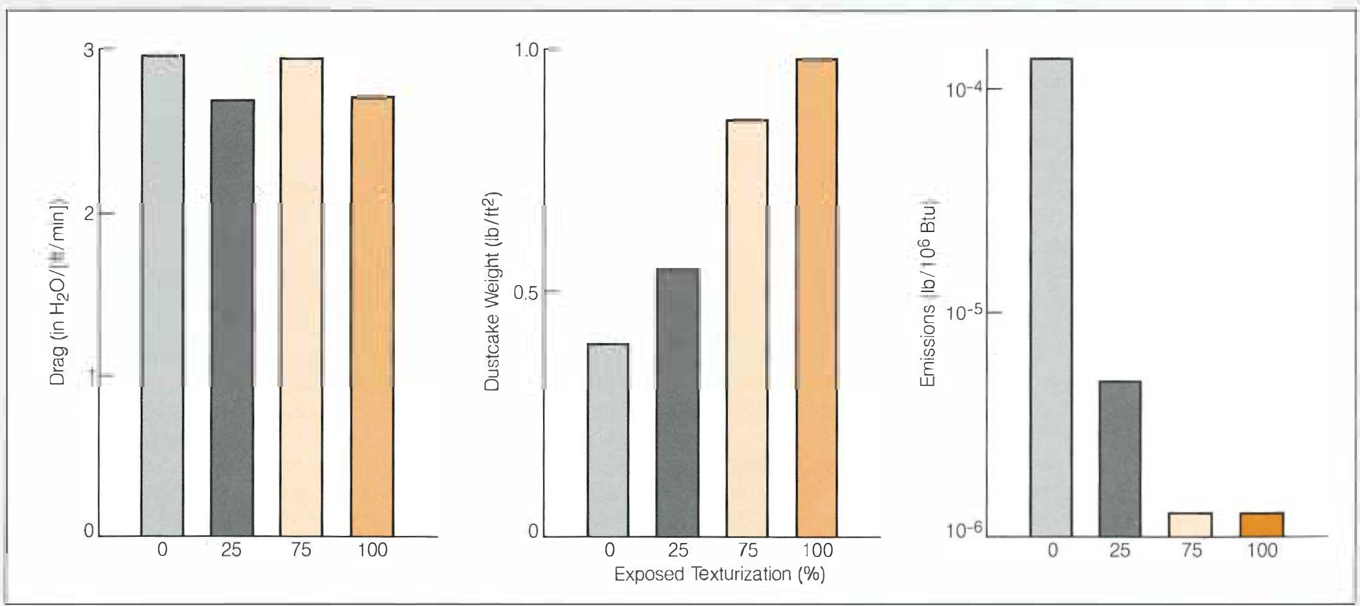
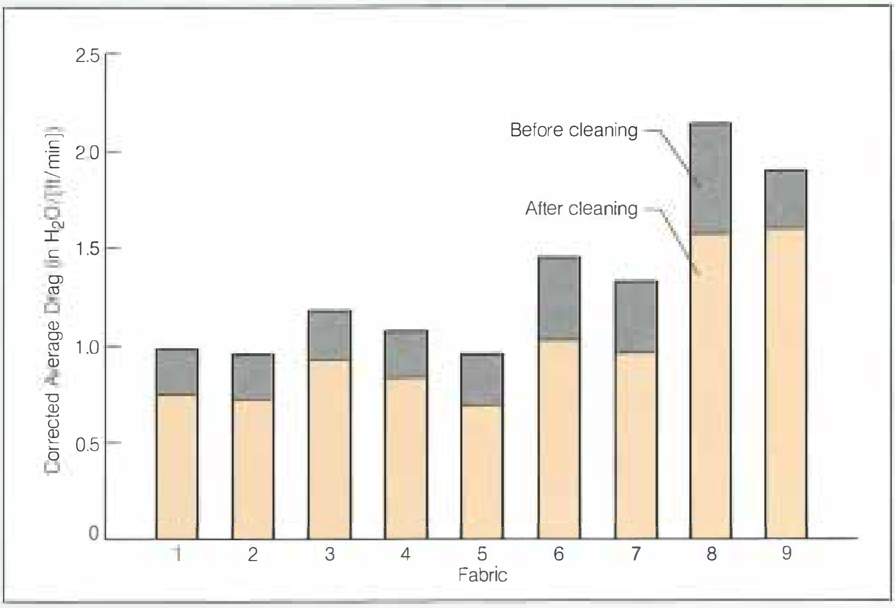


Figure 3 The effects of fabric texturization on filter bag performance were evaluated in a pilot baghouse; results are shown for 7000 hours of testing. The fabric with 25% exposed texturization showed the best overall performance under the test conditions.

hours of operation. The average drag (pressure drop divided by the air-to-cloth ratio) for the four filter bag types was essentially the same, about 3 in H_2O/(ft/min). However, there were significant differences in residual dustcake weight and in collection efficiency. Dustcake weight increased with exposed texturization, varying from 0.4 lb/ft^2 (2.0 kg/m^2) for 0% texturization to 1.0 lb/ft^2 (4.9 kg/m^2) for 100% texturization. The relatively high and undesirable dustcake weights observed for the 75 and 100% fabrics can lead to decreased bag life. Overall outlet emissions were very low in all cases—about 0.0001 lb/10^6 Btu or below, values representative of the well-controlled conditions in the pilot facility. However, particulate matter penetration in the filter bags with 0 and 25% exposed texturization was approximately 100 times and 10 times greater, respectively, than penetration in the other two bags. It was concluded that for the conditions typical of the pilot plant, the bags with 25% exposed texturization had the best overall performance. In contrast, filter bags with 75% exposed texturization have been the industry preference for subbituminous coal installations in recent years.

Figure 4 Filter bag fabrics of several different weaves were tested in the same compartment of a pilot baghouse; results are shown for 1000 hours, corrected to reference operating conditions (inlet fly ash concentration and air-to-cloth ratio). Conventional fiberglass materials (fabrics 1–5) generally showed lower drag than fabrics of unconventional materials or weaves (6–9) during the initial conditioning period.



Fabric screening studies

At its first meeting in February 1986, the manufacturers' advisory group for RP1129 developed specifications for 37 test filter bags spanning the range of commercially available fiberglass-based fabrics and including several novel materials. The group's constituent companies made the test bags at no cost to EPRI.

In August 1986, after installation of the IBFM system at the Arapahoe pilot plant, an experiment was initiated to evaluate the effects of fabric design parameters on performance. The four baghouse compartments were designated to contain filter bags of different yarn construction, texturization, finish, and weave, respectively. In addition, identical reference bags were installed throughout the baghouse to provide for the comparison of bags from different compartments. A standard bag used widely throughout the industry served as the reference bag. Over 1100 hours of testing had elapsed at the time of this writing. Final results will be available in mid 1987.

In the compartment where yarn construction is being studied, little difference in drag—either drag before cleaning or drag after cleaning (i.e., residual drag)—has been observed. At this time, all the fabrics are behaving similarly.

In the compartment dedicated to fabric texturization, minor differences in drag have been observed and a consistent trend is becoming apparent. In the early stages, drag is inversely proportional to the degree of texturization of the fill yarns. These results are generally consistent with those for the first 1000 hours of exposure in the earlier texturization experiment discussed above; that is, fabrics with lesser degrees of texturization (due to either yarn characteristics or fabric orientation) develop higher initial levels of residual drag. This could mean that particles penetrate deeper into less texturized fabrics. Drag will be monitored for the different fabrics as the bags and dustcakes equilibrate over the next 5000 hours to see if the drag levels equalize as they did in the earlier tests.

The performance of filter bags in the compartment dedicated to weave is illustrated in Figure 4. Filter bags 1–5 are all made of fiberglass with the same yarn construction and finish but with different weave patterns. The relatively minor variations in performance are likely due to the different amounts of exposed texturization resulting from the weave. Bags 6–8 feature materials and fabric construction less commonly used in filter bag applications. As of this writing, they differ significantly from the fiberglass bags in terms of average drag, components of drag, and residual dustcake weight. Bag 9 features a unique construction of fine, untexturized fiberglass yarns woven with an unusually large number of strands per square inch. The early performance of this fabric is also unusual in that it has a high level of drag but a low residual dustcake weight.

Yarn construction, texturization, and weave are properties of a fabric that, in general, can be specified by the buyer and obtained from any filter bag fabricator, fabric weaver, or fiberglass yarn company. In contrast, fabric finishes are unique to material vendors and are proprietary. Commercial finishes applied to the reference fabric are being directly compared in this experiment. So far all the filter bags are performing similarly.

Future work

High-sulfur-coal baghouse installations differ from low-sulfur-coal installations in terms of fly ash behavior and dustcake formation; consequently, optimal fabrics and filter bags may be significantly different for the two types of application. Studies similar to those at Arapahoe are being planned for the 10-MW (e) high-sulfur fabric filter pilot plant at Gulf Power Co.'s Scholz generating station. A compartment of the pilot plant containing 42 filter bags, each about 12 in (30 cm) in diameter and 35 ft (11 m) in length, will be modified for independent operation and equipped with an IBFM system. This program is expected to begin in mid 1987. *Project Manager: Walter Piulle*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

Narain G. Hingorani, Vice President

POWER SYSTEM PLANNING AND OPERATIONS

Composite system reliability

Reliability methods and techniques have been developed for separately evaluating the adequacy of either generating or transmission systems. Evaluating the reliability of a complete generation and transmission system has been unsuccessful because of the difficulty in arriving at consistent reliability indexes and analysis techniques. For example, a Monte Carlo simulation is used for generation reliability, whereas analytic approaches based on contingency enumeration and power flow analysis are used to evaluate transmission system reliability. Recognizing the needs of the industry in this area, EPRI initiated a 14-month scoping study in September 1985 with Public Service Electric & Gas Co. (RP2581).

The objectives of this scoping study were to analyze the purposes and uses of composite system reliability evaluation; to identify the reliability indexes of composite systems; to identify the solution methods, mathematical models, and computation tools; to determine the requirements of solution accuracy and acceptable computation efforts for the tools and techniques to be used for composite system reliability evaluation; and to identify the research needs in terms of methodologies and computation tools.

The contractor has completed the scoping study and the final report is expected to be published in early 1987. The study team concluded the following.

- Combined generating unit and transmission line outage events could contribute significantly to composite system unreliability; hence the need to evaluate composite system reliability.

- There is a strong need to show the industry the potential application of composite system reliability methods while these methods are being developed.

- The Monte Carlo methods are suitable for generation system details, such as generation maintenance, forced outages of generating units, and variations in load statistics, but they are not computationally efficient with serial computers to capture the less-frequent but severe transmission outages.

- The contingency enumeration methods can identify and test severe transmission outages, but they are computationally inefficient with serial computers to analyze in detail all the variations in system load statistics and generating unit status.

- A combined method with a Monte Carlo simulation for generation systems and contingency enumeration approach for transmission systems appears to be a possible alternative for composite system reliability evaluations.

Project Manager: Neal Balu

Optimal power flow research

Optimal operation of a power system implies balancing the cost of operation against security, reliability, and constraints on equipment operation. Because of the size and complexity of today's power systems, computer programs help system dispatchers and planning engineers arrive at optimal operating conditions. Not only real power flow but also reactive power flow and bus voltages must be scheduled if the power system is to be operated as efficiently as possible. Now, questionable fuel supplies, decreasing system reserves, and limited operating budgets have created conditions that must be simulated more accurately for proper resolution.

The goals of recent research were (1) to develop a set of requirements for optimal power flow (OPF) algorithms, (2) to determine the available algorithms, (3) to evaluate the most promising algorithms, (4) to make recommendations on which algorithm was best for which application, and (5) to report the results of the project. The first goal was accomplished by an industry survey that summarized the desired uses and needs of an optimal power flow code, including economic dispatch, megawatt loss minimization, interchange scheduling, system expansion, and VAR resonance allocation. The second goal was achieved by a literature search that indicated that although many algorithms existed, none was acceptable in its current form. Goals (3) and (4) ultimately concentrated on the development of a new algorithm for the solution of OPF by using a Newtonian approach.

This new algorithm not only is applicable to a very wide range of OPF problems but also is at least 50 times faster than previous algorithms. It is equally or more reliable. Solution time is approximately proportional to the size of the network being simulated, and the number of controls has little effect. Networks as large as 1000 buses have been modeled.

A paper describing this Newtonian algorithm was presented at the 1984 IEEE Winter Power Meeting in Dallas. It recently received an outstanding paper award from the IEEE. The final report for the project is available (EL-4894). ESCA Corp. was the contractor. *Project Manager: John Lamont*

Integrating load management and dispersed generation

Two projects were recently undertaken to integrate load management (RP2202-1) and dispersed generation (RP2336-1) into daily power system operation. Because of the similarity of the work on both projects, the work was coordinated through joint project review meetings.

The number of load management projects undertaken by individual utilities has increased from fewer than 50 in 1979 to more than 250 in 1984. As a result, there is an increasing need to integrate load management into daily system operations so that utilities can fully realize load management advantages and savings. However, few utilities have developed the tools necessary to integrate load management into their system load forecasting, generator unit commitment, load frequency control, and generator economic dispatch programs.

Energy and Control Consultants, Inc., has developed a research-grade IBM mainframe and personal computer FORTRAN program for analyzing the effective use of load management in daily operations (RP2202-1). Included in the program are the modifications needed in the generation unit commitment program to account for load management. When the unit commitment program is modified as described in the final report (EL-4688), it and the system load forecasting program, the load frequency control program, and the generator economic dispatch program can be used with an IBM mainframe and personal computer program to investigate load management alternatives.

Electricity generated by dispersed generation devices (cogeneration, wind turbines, small hydroelectric units, photovoltaics, fuel cells, and batteries) is increasing. These devices present a challenge to system operations because of their diverse and dispersed nature. In addition, their generation may not be monitored and is difficult to forecast. The devices are not controllable because they may be owned by a third party. As the amount of dispersed generation increases in a power system, utilities' inability to monitor and control that generation will result in poorer control of system frequency, voltage, inadvertent tie-line power flow, and increased utility costs if the utility must supply regulating power.

Systems Control, Inc., has developed a research-grade FORTRAN 77 computer program for analyzing the effective use of dispersed storage and generation sources in daily operations (RP2336-1). This program also has the modifications for the generation unit commitment program to account for dispersed generation.

When the unit commitment program is modified as described in the final report, EL-4957, it and the other system operation programs listed above can be used with the FORTRAN program to investigate dispersed generation use alternatives. *Project Manager: Charles J. Frank*

DISTRIBUTION

Failed cable analysis

Work designed to understand the causes of premature failures of distribution cables based on information available from utility records has been reported in earlier status reports (e.g., *EPRI Journal*, December 1983, p. 53), EL-3154, and EL-3501. This information and prior work from laboratory-accelerated aging tests provided evidence that cables insulated with high-molecular-weight polyethylene (HMWPE) exhibit an inverse ac breakdown (ACBD) strength-operating stress relationship—that is, the higher the operating voltage stress, the lower the remaining ACBD when such cables are recovered and tested in the laboratory.

It has been generally assumed that cables insulated with XLPE insulation respond similarly, but initial work on RP1782 indicated that parameters influencing aging appeared to differ for the two insulation types. Table 1 illustrates the point. Material nature and age are the most important parameters influencing cable life.

For HMWPE, voltage stress was next in importance. Further, for HMWPE exposed to voltage stress under 50 V/mil (1.97 kV/mm), insulation wall thickness was next in importance: the thicker the wall, the lower the failure rate. For HMWPE subject to high stress, year of installation was the factor next in importance.

For XLPE, the factor after age was wall thickness, thicker cables having lower failure rates. Following thickness was year installed. Voltage stress did not appear to be a highly ranked factor related to XLPE failure rates.

It is possible that deficiencies in the data provided to the contractors (Battelle, Columbus Laboratories) caused them to draw incomplete conclusions, so the results were confirmed by performing electrical breakdown testing on several recovered service-aged XLPE insulated cables; in addition, materials tests were performed to help understand the information developed. Battelle completed the materials tests and the Institut de Recherche de l'Hydro-Québec determined the electrical breakdown behavior.

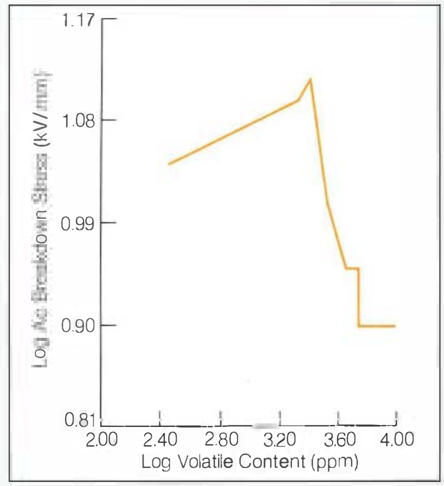
Six utilities participated by providing eight cables of two wall-thickness ranges that had been service-aged for 6–11 years. The results indicate a complex relationship between operating stress, wall thickness, and volatiles in the cable (Figure 1); no strong relationship between ACBD and field-operating voltage stress was observed (as it had been for HMWPE-insulated cables). It should be emphasized that the conclusions are influenced by how the electrical breakdown data are treated (i.e., whether termination failures are included and how the information is treated statistically).

Table 1
IMPORTANT FIELD CABLE PARAMETERS AFFECTING FAILURE RATES

	Parameter	
Rank*	XLPE	HMWPE
1	Insulation material	Insulation material
2	Age	Age
3	Wall thickness	Voltage stress
4	Year installed	Wall thickness, low stress; year installed, high stress

*Relative importance.

Figure 1 This figure shows an apparent relationship of ACBD strength of field-aged XLPE-insulated cables with residual volatiles (moisture, cross-linking-aged by-products); the greater the residual volatiles, the lower the ACBD.



Regardless, the service-aged cables displayed three major characteristics: lower ACBD strength than newly prepared cables (supporting both earlier observations and accelerated-aging test results), relatively high volatile contents, and nonuniformity in property behavior along the cable length. Of interest is the observation that where a halo was observed (halos are cloudy bands within the insulation wall composed of liquid-filled microvoids, ranging in size from about 1 to 25 μm), an inverse correlation was observed. When the total volatiles were taken into account (halos were observed only when the volatiles were greater than 2200 ppm), a clearer relationship was apparent (Figure 1).

Although halos have been observed in the past, no correlation between halos or volatiles and breakdown strength has ever been reported. Halos are composed of water and cross-linking-aged by-products and have not been reported for HMWPE-insulated cables.

Materials tests also showed that the oxidation-resistance behavior of XLPE-insulated cables is much more complex than that of cables insulated with HMWPE. A single oxidation behavior mode exists for HMWPE, but three different modes were apparent for XLPE. This is believed to result from the cross-linking process where peroxide-antioxidant-polymer interactions, which cannot take place in HMWPE insulation, can occur.

These results confirm how the different operating stresses influence XLPE- and HMWPE-insulated cables. They are also helping to focus attention on the causes for the different observed behavior of XLPE- and HMWPE-insulated cables during field aging; volatiles, oxidation resistance, and morphology differences (*EPRI Journal*, December 1984, p. 54) all contribute to the different ACBD responses of XLPE- and HMWPE-insulated cables during service aging. Some of these results were presented at the 1986 International Symposium on Electrical Insulation. *Project Manager: Bruce Bernstein*

UNDERGROUND TRANSMISSION

Aging of premolded splices

One of the more serious problems in the use of extruded dielectric transmission cable, 69 to 138 kV, is splice reliability. Past accelerated-life testing at several facilities (especially EPRI's Waltz Mill site) and actual field experience of numerous users indicate splices have been less than adequately reliable, are sensitive to detrimental environment conditions, and need very skillful construction. To address these problems, EPRI funded research aimed at developing a simplified 138-kV splice that emphasized reliability and quick installation (RP7815). The end product of this research is a factory-molded and factory-tested splice developed by Elastimold Div., Amerace Corp. (Figure 2) that delivers high reliability and minimal assembly time and requires average splicer skill.

Severe accelerated-life testing of 12 splices in varying environments at EPRI's Waltz Mill facility was conducted recently. Posttest analysis indicates that these splices performed well beyond expectations, met their objectives, and amply demonstrated their qualification for reliable utility service.

Three test bays provided a range of test conditions for the splices. Because water can adversely affect extruded insulating materials, its influence was taken into consideration by operating one test bay filled with water at all times (with the splices fully submerged), one test bay dry at all times, and one alternately dry for one week and wet for one week for the duration of the test program. These bays are referred to as the wet, dry, and alternate bays, respectively. Figure 3 shows the layout in each test bay.

The two cable ends of each bay were terminated in potheads that were bused together so that the splices, cable, and potheads formed a complete loop. The potheads were also connected to the high-voltage bus. Five current transformers were used to supply load current. This arrangement made it possible to control the conductor current while independently applying high voltage. In this way, each temperature and voltage level called for in the test program could be established independently. Test temperatures were monitored appropriately.

A shield interrupt was made in the cable on each side of every splice so that measurements of corona discharge and dissipation factor could be made individually on each splice. In addition, at each test level the sample was run for one period at a constant temperature, while in the next period the sample was heated to the test condition, then allowed to cool to near ambient. These two periods are referred to as continuous and cyclic, respectively. Voltage was maintained at a constant level during each test period.

The planned test program for the splices was similar to the program established for all extruded dielectric cable samples. The cumulative scheduled test time was 64 weeks, with all three test bays run simultaneously.

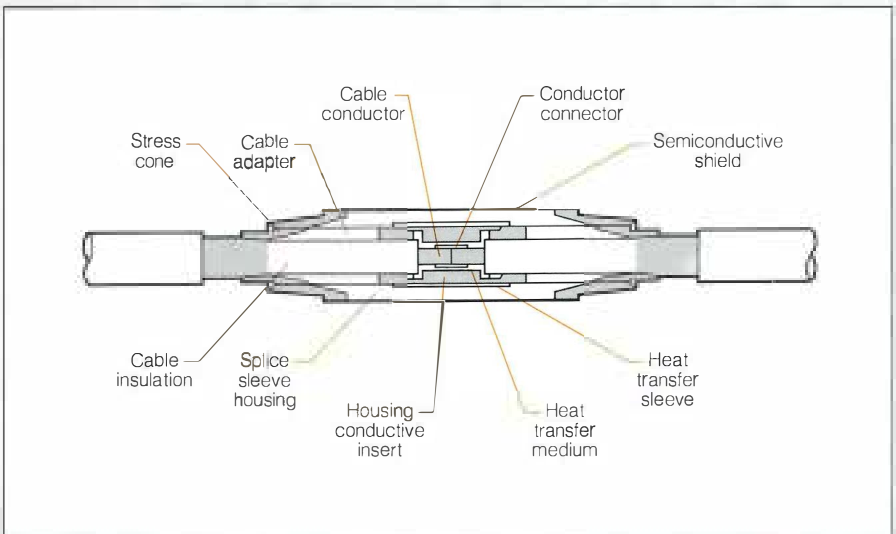
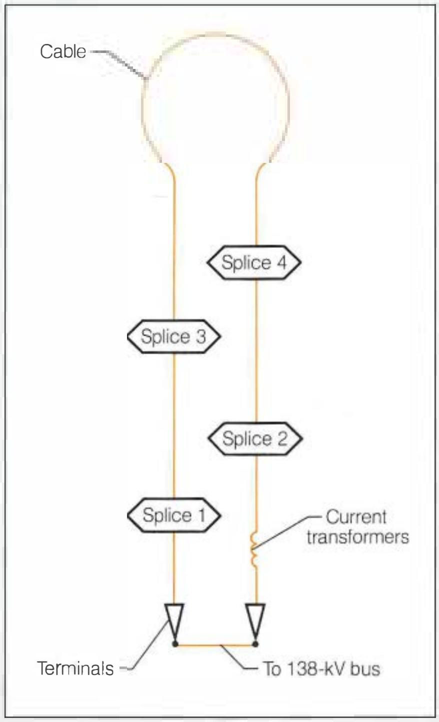


Figure 2 Cutaway of 138-kV splice assembly showing principal components.

Figure 3 Schematic of Waltz Mill test showing arrangement of splices, cable, and voltage and current samples.



The cyclic tests on all three test bays were scheduled to run on a 24-h cycle, with an 8-h heating period and a 16-h cooling period.

Corona and dissipation factor measurements were made at the end of each test period throughout the program. These measurements were made at ambient temperature and at all of the test temperatures and voltages up to the levels of the next test period.

The most important result of this phase of the test program was that no failure occurred in any of the 12 splices tested. In addition, none of the corona (occasionally observed) could be traced directly to a splice. The overall severity can be judged by the occurrence of severe corona in two potheads, a pothead failure, and two cable failures.

The assembled splices were returned to the manufacturer for 60-Hz ac breakdown tests, impulse tests, and physical measurements. Acceptable breakdown levels were obtained on the electrical tests; specific details are in IEEE paper 86 T&D 585-4.

Regarding physical measurements, there was some concern that the interference fit of the components might decrease with time and with higher operating temperatures. The reverse was found to occur: actual measurements show that the cable diameter increased in the critical electrical stress areas. This finding was surprising and contrary to some expressed concerns. The insulation diameter increased because the cable insulation expands more than the aluminum heat transfer sleeve (Figure 2) during a heating cycle, and the filler tape under the sleeve expands longitudinally at the same time. Both of these actions increase the cable diameter in the high electrical stress areas of the splice, a very beneficial action. Specific details of this finding are in IEEE paper 86 T&D 585-4.

The following is a summary of the Waltz Mill tests and posttest evaluations.

- Acceptable breakdown values were obtained on cycled splices.
- The source of low corona levels could not be positively identified but probably is at the shield breaks in the cable. The three samples tested after the cable shield breaks were removed and the cable shields restored showed significant improvement.
- The cable insulation diameter increased in the splice stress areas after cycling with conductor temperatures up to 130°C.
- No significant differences in performance were observed between the splices in the dry, wet, or alternate test bays.
- The splices performed beyond expectations and amply demonstrated their qualification for reliable utility service.

Project Manager: John Shimshock

TRANSMISSION SUBSTATIONS

R&D needs for converter stations

HVDC transmission today has a design limit of 600 kV. Researchers worldwide have been investigating designs for dc transmission lines that can carry voltages up to 1500 kV and cables that can carry voltages up to 800 kV. However, little information is available on the converter station equipment that must undergo dc stresses. But the use of higher-voltage HVDC transmission will depend on the industry's ability to build converters of the appropriate size. This project evaluated the key equipment R&D needs for a converter station in a very high voltage dc transmission system (RP2115-5).

Researchers conducted a thorough survey of the technical literature of the various fields pertinent to the development of converter stations for 800-, 1000-, and 1200-kV pole-to-ground voltage ratings. Using simplified equipment specifications as the basis for discussion with suppliers of converter station equipment, as well as with utilities that have an interest in HVDC systems, the researchers arrived at a set of technical impediments that have to be resolved before the converter station technology can be extended above 600 kV.

Researchers reached these conclusions.

- Building 800-kV converter stations by extrapolating from present knowledge and experience appears feasible, although R&D could contribute to economic designs and optimal performance, including reliable operation.
- Building 1000-kV converter stations from present knowledge appears feasible, but extensive R&D will be required to achieve economically viable designs with proven reliability.
- On the basis of currently available knowledge and experience, 1200-kV converter stations do not appear to be practical. However, in-depth research could change this conclusion.

An HVDC transmission system with a pole-to-ground voltage of 600 kV (1200 kV pole to pole) has been built in Brazil. In addition, the utility industry is showing great interest in 800-kV systems and in current research on transmission up to 1500 kV. This technology assessment study is part of a larger study of converter stations for voltages above 600 kV. A companion EPRI project has identified the system design constraints in general (EL-3892). This study confirms that HVDC transmission will require long-term R&D. However, although building 800-kV technology by applying existing 500–600-kV designs appears feasible, extending current designs to 1000- or 1200-kV systems appears impractical at present. *Project Manager: Stig Nilsson*

Radio interference from HVDC converter stations

HVDC converter stations inherently generate electromagnetic interference (EMI), which can hamper communication systems. Voltage collapse over the converter circuitry at the firing of each valve in the valve hall generates EMI. The pulses are conducted through the bushings (in spite of the valve-hall shielding), along the buses connecting the valve hall to the ac and dc switchyards, and finally along the transmission lines, all of which radiate EMI. This interference can be particularly troublesome in urban areas and is therefore of concern to utilities.

The objective of this project is to understand how this radio frequency (RF) noise is generated and to develop a generic computer program to predict RF effects around converter stations (RP1769).

A generic computer model has been designed for predicting electromagnetic noise. It has been used to predict the RF noise generated in the 5–500-kHz range at the Dickinson converter station in Minnesota and validated by comparing the results with RF spectra measured at the station. The key feature is the use of measured RF impedances of actual equipment in the model rather than idealized components. Further, data from a modified version of the physical scale model of the Dickinson converter station gave reasonable agreement with the calculated results.

Using the generic computer program, engineers can compare the RF performance characteristics of suggested converter station designs before construction and modify their designs at the outset.

The generic computer program can be used to calculate various RF quantities at any location inside the converter station. It can also be used to calculate the RF ground-level electric field strength and magnetic flux density, not only inside but also outside (close to) the converter station. This should normally be a part of the specifications for a converter station design. The computer program is also useful in the design and optimization of RF filters. *Project Manager: Selwyn Wright*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Vice President

IMPACT OF DSM PROGRAMS ON THE T&D SYSTEM

Many utilities are actively pursuing demand-side management (DSM) measures as a way to achieve a combination of energy efficiency, load management, and customer productivity improvement goals. Some studies have been conducted to evaluate the power system effects of various DSM options, but most have considered only the generation system; the transmission and distribution (T&D) system was assumed to be unaffected. Recent experience suggests, however, that this premise should be reexamined. For example, a European utility with a very successful customer heat storage program had to limit participation in certain areas to avoid exceeding the night time load-carrying capability of its distribution system. In contrast, a U.S. utility has used direct load control to avoid costly reinforcement at a transmission bottleneck. Thus the T&D system can be a source of opportunities or problems in implementing DSM. To improve our understanding of how DSM can affect T&D, EPRI is sponsoring research to identify the critical issues involved, to develop engineering and planning methods for designing DSM strategies that maximize T&D benefits, and to establish a body of knowledge through case studies (RP1979, RP2548).

Most DSM programs involve managing the customer's load in order to make more productive use of electricity and to lower the cost of energy services. These programs achieve generation system savings through reduced energy costs and reduced capacity costs. T&D benefits could also be achieved through reduced energy costs (i.e., by lowering T&D losses) and reduced capital costs (by deferring T&D capacity increases). T&D losses represent about 8% of total generation; T&D capital expenditures are, on average, about 40% of total utility capital expenditures. Thus, on the basis of costs alone, DSM effects on T&D should not be ignored.

The T&D system presents DSM opportunities and challenges that are altogether different from those of the generation system. The major opportunities are as follows.

- The capacity factor of the T&D system is much lower than that of the generation system; hence measures to improve the overall utility system load factor offer great opportunities for increased T&D capacity utilization.
- T&D capacity expansion can occur in large increments, most often at bottlenecks; strategic targeting of DSM to defer such expansion can yield significant T&D savings.
- Incremental T&D losses are approximately proportional to the square of the load carried; thus DSM options that either reduce load or shift it from peak to off-peak periods will reduce T&D losses.

Now is the best time to exploit such opportunities because utility T&D expenditures are growing. (They are expected to exceed generation expenditures by the early 1990s.) Among the challenges involved are the following.

- The load of the T&D system peaks at different times than the generation system load; a DSM strategy aimed at reducing total system costs may have to compromise between generation peak reduction and T&D peak reduction.
- The T&D impacts of DSM are heavily influenced by both the customer and T&D characteristics of a local area. Because an effective DSM strategy has to be tailored to local needs, analyzing and implementing the strategy are complex tasks.
- T&D analyses are more time-consuming and much less standardized than analyses of the generation system; hence the development of T&D planning approaches is more difficult.

EPRI is sponsoring research to help utilities meet the challenges involved in designing DSM strategies that will maximize T&D benefits. The project has two phases. The main objective of phase 1, which has been completed, was to develop a comprehensive T&D planning guide and a computer code for screening DSM options in terms of T&D effects. Selected options, including heat pumps, residential thermal storage, and commercial cool storage, were evaluated as part of this effort. The main objectives of phase 2, now under way, are to introduce the T&D planning guide to utilities and to build a base of knowledge through case studies.

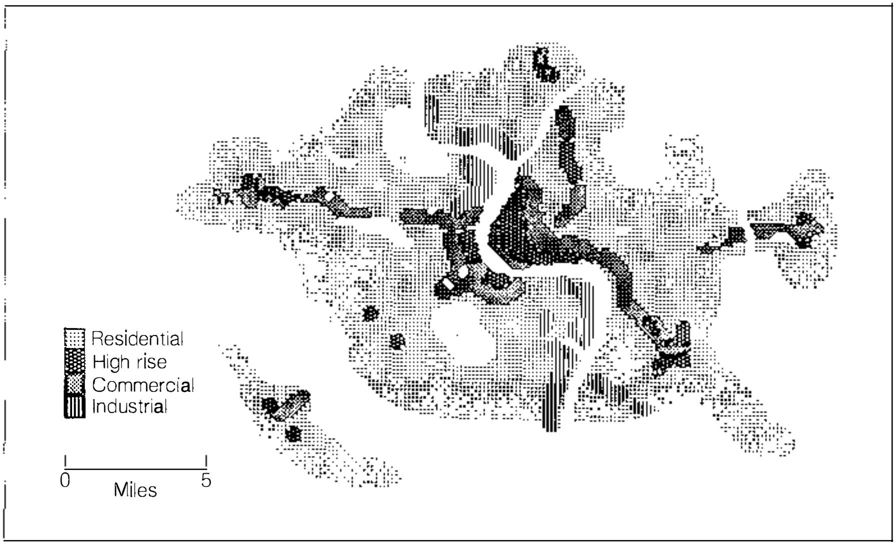
Screening tool

Planning a T&D system is a very complex process. A comprehensive evaluation of the T&D impacts of DSM would have to take into account (1) load density and load shape by customer class, as well as the geographic distribution of classes (Figure 1); (2) changes in load characteristics for each customer class as a result of DSM policies and control strategies; and (3) the effects of changes in load characteristics on the T&D system (i.e., effects on stability, equipment loading, losses, voltage regulation, and system protection).

Many load forecasting and load research techniques are available to identify system load characteristics and how they change as a result of DSM. Thus the first steps of a T&D analysis pose no significant problems. The analyst has only to make sure that the load forecasting tools are properly interfaced with the T&D planning tools.

The analysis of potential T&D impacts, however, is complicated and time-consuming. Traditional T&D planning studies are extremely detailed and require considerable manpower to develop. This level of detail is necessary to pinpoint the T&D changes required to meet load growth over the planning horizon (typically 10 to 20 years). In contrast to the slow, evolutionary changes in load characteristics resulting from load growth, changes due to major DSM options tend to be sudden and sizable. Such changes impose a different set of

Figure 1 A utility's customers are not evenly distributed throughout its service area but tend to be concentrated by type. To estimate the effects of DSM options on the T&D system, utility planners must simulate DSM-related load shape changes by customer class and then use data on the geographic distribution of customers to locate load changes with respect to T&D equipment.



requirements on the T&D system. DSM impacts can be reliably assessed through traditional T&D analysis, but significant amounts of data, manpower, and computer time are required. Using this approach can prove too burdensome for a utility considering several candidate DSM options and implementation and control strategies. A more efficient planning method is needed.

One solution would be to apply a simplified screening approach to eliminate a large number of undesirable DSM alternatives. Unfortunately, most simplified screening methods for T&D planning have not proved sufficient. Several earlier studies used simplified approaches to evaluate the impacts of DSM on T&D, but the results did not meet acceptable accuracy standards. In phase 1 of the EPRI project, Westinghouse Electric Corp. undertook to develop an accurate screening tool for this purpose.

The screening approach adopted by Westinghouse uses an innovative technique called spatial frequency analysis (SFA) to estimate the total impact of DSM strategies on each level of a utility's T&D system—transmission, subtransmission, substations, primary feeders, laterals, and secondary feeders. The SFA technique has much lower data and manpower requirements than traditional, detailed methods because it features a stochastic model of feeder switching, substation service areas, and T&D configuration. Whereas the detailed methods represent these explicitly, the stochastic SFA method models them as probability functions. A load density map of changes in loading throughout the utility system is produced, and the probability functions are applied to these geographic data to determine if feeders, substations, and other T&D components can be reconfigured to maximize the benefits (or minimize the negative effects) of the DSM option.

The SFA method typically requires less than 8% of the data and manhours of traditional methods. To speed up the calculations, it uses a number of signal-processing techniques originally developed for the enhancement of space-probe television pictures. These spatial-frequency-based algorithms perform the analysis very quickly and can be applied by using one of several public-domain computer programs (such as those from NASA and IEEE).

To test the reliability and accuracy of the SFA technique, Westinghouse conducted case studies on four utility systems and compared the results with those obtained by traditional T&D planning methods. The four utilities (three U.S. and one European) were chosen to represent diverse system conditions and T&D design philosophies. The cases included urban and rural systems, summer-peaking and winter-peaking loads, high and low growth rates, and a wide range of DSM market penetration rates. The SFA results agreed closely with results from the detailed analyses, as Table 1 illustrates for one case.

Phase 1 findings

The phase 1 work has yielded many insights, both about the broad effects of DSM on T&D and about the specific effects of certain DSM options. For the purposes of considering broad effects, the T&D system can be thought of as having three distinct levels with different sensitivities to DSM changes.

□ The transmission system. This level is characterized by fully diversified loads and hence by the same type of DSM effects as the generation system.

Table 1
SFA SCREENING VERSUS DETAILED ANALYSIS: PROJECTED DSM EFFECTS
(% increase)

DSM Option and Market Penetration	Utility System Peak Load	Subtransmission Capacity SFA	Subtransmission Capacity Detailed	Substation Capacity SFA	Substation Capacity Detailed	Feeder Capacity SFA	Feeder Capacity Detailed
Residential heat pumps							
100%	30	40	35	53	49	72	61
50%	0	1	0	4	4	8	7
25%	−12	0	0	0	0	2	0
Residential thermal storage							
100%	118	120	120	160	144	170	153
50%	40	44	42	55	48	60	51
25%	0	0	0	4	3.5	7	6.5
Commercial cool storage (50%)	−5	0	0	0	0	1	1

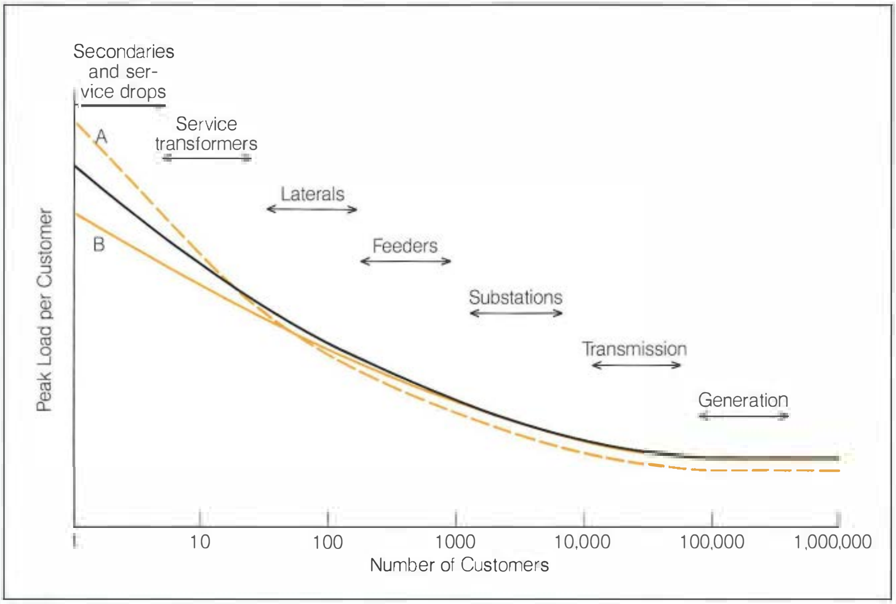
◻ The subtransmission-substation-feeder portion of the system. Load behavior at this level is sufficiently aggregated that load curves are essentially smooth and differ little between units of equipment serving the same customer class. However, this level is influenced by the geographic distribution of customer classes in the service territory.

◻ The lower level of the distribution system—laterals, service transformers, secondary circuits, and service drops. This equipment serves at most a handful of neighboring customers, usually all of the same class. Thus it is highly sensitive to the coincidence of demand among individual customers and even to the coincidence of demand among appliances and major loads for a single customer.

The project found that DSM strategies aimed at reducing the peak load of a customer class will usually result in significant benefits for the larger elements of the T&D system (e.g., feeders, substations, transmission equipment). No generalization can be made about the effects on smaller equipment (e.g., laterals, service transformers); in some cases they were positive and in others, negative. In contrast, DSM strategies that seek to reduce system load by shifting (rather than lowering) customer-class peaks may have a negative impact across the entire spectrum of T&D equipment.

Laterals, service transformers, secondary circuits, and service drops are highly sensitive to the way direct load control and storage options are implemented. Slight changes in control strategy or in the geographic distribution of DSM customers, although having no impact on system load, may significantly affect this equipment. Figure 2 illustrates the effects of two DSM options on the different T&D levels.

Figure 2 The effects of a DSM option on T&D loading vary by system level, as the two examples here illustrate. The black curve shows normal system loading. Option A increases loading on the equipment that serves the fewest customers while reducing it on the higher-level equipment; option B reduces loading on the distribution system without affecting transmission (or generation) loading.



The project also yielded valuable information on specific DSM options. It concluded, for example, that the penetration of heat pumps into a utility service area will significantly affect the distribution system. The impact is sensitive to a number of factors (e.g., annual load factor, T&D system structure, system economics) and cannot easily be generalized. In every utility system, there is some amount of heat pump penetration that can be absorbed by the distribution system without major reinforcement; this amount may vary from as little as 30% to over 60%. The interlocking of heat pumps and electric water heaters can yield benefits for service transformers, secondary circuits, and laterals and lessen the need for reinforcement as heat pump penetration increases.

Thermal storage devices are potentially a very effective method of flattening a utility's load curve. In every case studied, there was some amount of residential thermal storage that would benefit the T&D system. A rule of thumb is that the effect is mainly positive up to a penetration of one in three customers. After that, it depends on several factors that cannot be generalized. At some penetration (usually over 66%), substantial reinforcement of the distribution system may be required if thermal storage shifts the heating load to the early morning hours. (In contrast to the T&D system, the generation system may be able to absorb and benefit from 100% penetration of thermal storage into one or more classes.)

Commercial cool storage also yields benefits for distribution systems at lower penetration rates; moreover, unlike residential thermal storage, it has little negative impact as penetration increases. There are two reasons. First, most commercial loads are larger, often requiring dedicated transformer banks and laterals; thus there are few lower-level demand coincidence effects. Second, in most power systems, predominantly residential feeder and substation service areas greatly outnumber predominantly commercial ones. Residential thermal storage can have negative effects when a feeder or a substation serves residential load almost exclusively. Most commercial loads outside of the downtown area are on mixed commercial-residential-industrial feeders, which have a load curve more like the total system load curve and which can absorb higher cool storage penetration without adverse impact.

Finally, demand-limiting devices generally have a very large positive effect on lower-level distribution system equipment, although their effect on the transmission system is negligible.

Future work

Originally this project was limited in scope and addressed only a few important DSM strategies. As a result of an organizational consolidation of end-use activities at EPRI, it has been expanded to cover a more comprehensive set of DSM options. The consolidation promises to greatly streamline technology transfer and to facilitate the merging of the SFA technique with several codes used to determine changes in system load characteristics due to DSM.

Southern Engineering International is the primary contractor for the phase 2 effort, which focuses on technology transfer. SEI is a subsidiary of the Southern Company, a utility that is actively pursuing DSM options. Gulf Power Co. will be the first host utility.

When completed in mid 1987, this project will provide the industry with a planning guide and a screening tool that can zero in on the most promising DSM options in terms of T&D effects. Also, the case studies will be a rich source of information about the opportunities and problems associated with DSM implementation and about strategies for achieving optimal generation and T&D benefits. *Project Managers: Timothy S. Yau and William M. Smith*

R&D Status Report
ENVIRONMENT DIVISION

Stephen C. Peck, Acting Director

ESTIMATING EXPOSURE TO ELECTRIC FIELDS

With increased concern about public exposure to the extremely low frequency fields generated by transmission lines has come the need for a method of estimating and evaluating exposure. EPRI's Environment Division has sponsored a project with Enertech Consultants to study ac field exposure and to provide researchers with measurement and modeling tools (RP799-16). One of the tools developed in this project is a versatile, easy-to-use software package called EXPOCALC.

The result of two years of field research, exposure measurements, laboratory experiments, and testing, EXPOCALC is an integrated software package for quantifying and characterizing electric field exposure. It is made up of five modules: the main driver, a calculation module for mapping unperturbed electric fields, a module that adjusts electric field values to account for the presence of objects, an electric field contour plotting module, and an exposure tabulation module.

EXPOCALC incorporates an activity systems model for studying the relationship between people's activities and their physical environment. When coupled with technical methods that model the electric field environment near transmission lines, the activity systems model provides a reasonable basis for estimating human exposure to transmission line fields.

Activity systems modeling is a method researchers have used for more than a decade to study human activity patterns in urban areas, to analyze transportation behavior, and to estimate exposure to indoor and outdoor air pollutants. Such studies associate the location and time of activity with the social or physical conditions of interest.

The time spent in the area of a transmission line is the primary focus of EXPOCALC. Creating an activity systems model for human exposure to 60-Hz electric fields requires first that the physical geography be characterized. Next, the pattern of human activities must be mapped onto this geography to determine the time spent at particular locations. Then this information is combined with electric field information to develop exposure estimates.

EXPOCALC can be used to evaluate exposure during three basic types of human activity.

- Distributed activity extends relatively uniformly over a land surface—for example, farming or mowing a yard.
- Linear activity extends along a path or route —for example, hiking, jogging, or bicycling.
- Point activity is confined to a specific location or position—for example, sitting on a park bench.

Researchers have found that actual, measured exposure to electric fields is usually considerably lower than predicted exposure. Many factors contribute to this difference, but among the most important are body position, relative grounding during an activity, and shielding provided by equipment or objects. EXPOCALC uses experimentally determined activity factors to correct this problem. An activity factor is the ratio of actual exposure during an activity to the exposure that would be measured in a theoretical reference condition for the same exposure time and the same unperturbed electric field. The reference condition assumes that the electric field is uniform and that the person is standing erect on conductive, flat ground. On the basis of numerous exposure measurements made throughout the United States near lines ranging from 115 to 1200 kV, the Enertech investigators have developed a table of activities and their associated activity factors for the software package.

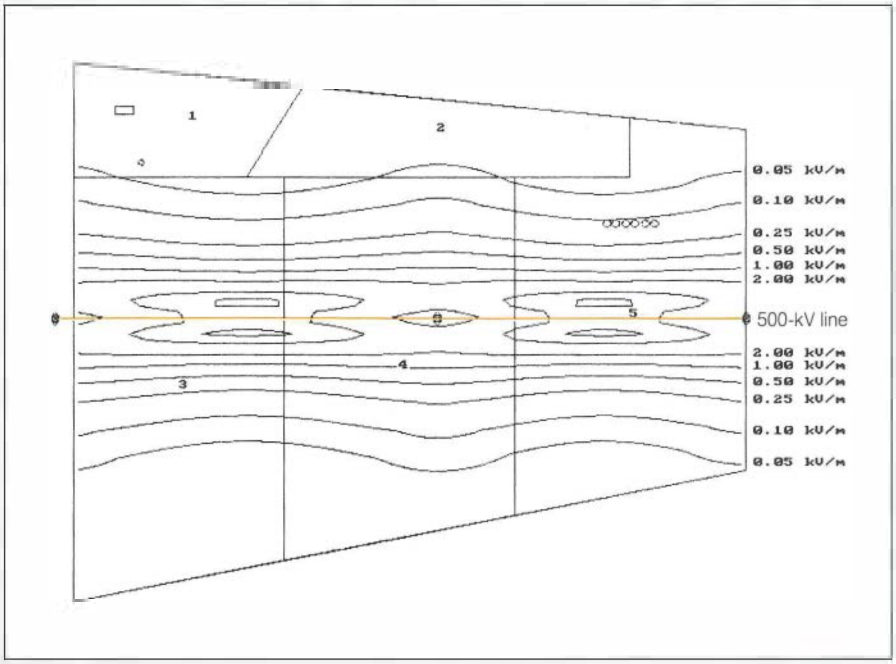
EXPOCALC has several unique features that make use of new algorithms. One is its ability to perform shielding calculations. Grounded objects, including transmission line towers, can significantly lower the electric field in their vicinity as a result of shielding. EXPOCALC uses a set of algorithms, based on recent EPRI research at the High-Voltage Transmission Research Center, to account for shielding effects. The algorithms model four basic types of objects: boxes (objects such as buildings and cars), rows of trees, single trees, and vertical cylinders (objects such as silos and water towers). The shielding calculations are optional; hence EXPOCALC users can obtain exposure estimates with and without shielding adjustments for comparison.

Another unique feature of EXPOCALC is its ability to produce electric field contour maps for an area, using contour intervals (in kilovolts per meter) specified by the user. A code within EXPOCALC is provided to handle various contour plotting problems, including saddle points, missing data, and high and low values close together. Figure 1 shows a contour map produced by EXPOCALC for a 500-kV transmission line running through a farm.

The ac electric field computational code used in EXPOCALC is based on the two-dimensional charge simulation method. This commonly used approach essentially involves two steps: calculation of equivalent charges per unit length of conductor and calculation of the electric field produced by these charges. The method's assumption of infinitely long conductors parallel to the ground introduces error—particularly in the region near towers, where the slope of the conductors increases dramatically. Thus an algorithm was developed for EXPOCALC to account for the effect of line sag near towers. It is based on comparisons of calculated and measured fields for several transmission lines and on three-dimensional modeling of conductors at the High-Voltage Transmission Research Center. EXPOCALC also contains algorithms to account for angles in a transmission line.

EXPOCALC assigns an electric field value to a given point on the basis of (1) the point's proximity to the line and (2) the field values produced by all line segments influencing that point. It generates a table of electric field values for use in determining the field at any given grid point within a study area. The values are computed for conductor heights ranging from

Figure 1 Typical electric field contour map produced by EXPOCALC. This example involves a farm crossed by a 500-kV transmission line; the five numbered areas have different crops.



the minimum ground clearance of all spans to the height of the highest tower attachment point. The height increment is specified by the user. The maximum lateral distance is based on the description of the study area.

A rectangular grid of electric field values is superimposed on the study area grid. Exposure is calculated from the time associated with the given activities (supplied by the user), the area associated with each grid point, and the electric field associated with each grid point. Exposure can be presented as a histogram of field strength versus time or as an exposure integral in kilovolts per meter hour ([kV/m]·h). The exposure results can also be sorted into user-selected ranges and presented in tabular form; Table 1 shows results for a farming example.

EXPOCALC is designed for use on an IBM PC and comes with a 230-page user's manual that outlines both the program's operation and underlying theory. EXPOCALC's user-friendly interface offers full-screen editing of all input data, on-line help messages for all input items, the ability to load data from an existing file, and many other popular microcomputer features. EXPOCALC prints out all tables and graphs generated within the program and can also store all data on disk for later evaluation. Most program options can be selected with a single keystroke, and most have default answers. Designed with the inexperienced computer user in mind, EXPOCALC nonetheless provides a sophisticated evaluation tool.

Possible applications of the EXPOCALC software package include assessing exposure abatement or reduction strategies, preparing environmental reports, developing exposure estimates for comparison with laboratory results, and facilitating the communication of technical details (e.g., through electric field mapping).

EPRI members can obtain EXPOCALC free of charge through the Electric Power Software Center. Also, Enertech Consultants has a commercialization license for distributing the software. *Project Manager: Robert Black*

Table 1
SAMPLE EXPOSURE RESULTS

Exposure Range (kV/m)	Time (h/yr)	Time-Weighted Avg E_{eq}* (kV/m)	Annual Exposure (kV/m) · h	Annual Exposure % of total	Area (acres)	Area-Weighted Avg E† (kV/m)
0–0.05	516.16	0.017	8.654	18.4	18.47	0.024
0.05–0.10	15.51	0.067	1.037	2.2	5.77	0.071
0.10–0.25	13.95	0.161	2.241	4.8	5.85	0.161
0.25–0.50	5.89	0.363	2.141	4.5	3.35	0.354
0.50–1.00	5.40	0.745	4.020	8.6	2.92	0.709
1.00–2.00	7.22	1.444	10.423	22.2	2.54	1.418
2.00–6.00	6.22	2.803	17.435	37.1	5.81	3.713
6.00–10.00	0.15	7.046	1.039	2.2	1.66	7.135

*Equivalent electric field—takes into account activity factors.
†Electric field—does not account for activity factors (i.e., assumes grounded, upright posture).

RESEARCH ON ORAL/NASAL BREATHING

Inhalation is one of the primary means by which humans take up chemical agents from the environment. It is impossible to quantify that uptake without first understanding the mechanisms at work. The nose and the mouth play somewhat different roles in the delivery of gases and airborne particles to the lungs. EPRI-sponsored researchers have developed a new system that can measure the extent to which the body makes use of each of these pathways (RP1225-3). It promises to provide valuable data for the study of human exposure to airborne pollutants and any resulting health risks.

Air flowing in and out of the human respiratory tract can pass through the nose or through the mouth. Although these upper airways join at the back of the throat and thus have a common connection to the lower airways and the lungs, there are important functional differences between them. One key difference is the extent to which each is used in normal breathing at rest and during exercise.

At rest, most of us breathe primarily through the nose unless this route is blocked by an anatomical defect or by a temporary condition, such as a cold or hay fever. When we exercise in the course of work or recreation, the body's need for oxygen increases. To meet this need we must inhale more air per unit time: in physiologic terms, we must raise our minute ventilation (a measure of breathing expressed in liters per minute). Normally we can do this by continuing to breathe through the nose but taking faster and somewhat deeper breaths. With sufficiently strenuous exercise, however, nasal breathing alone can no longer supply enough oxygen, and we must augment it by inhaling some air through the mouth. The level of minute ventilation at which oral breathing begins is called the crossover point. Thereafter, in general, the proportion of oral to nasal breathing increases with rising minute ventilation up to a point where it becomes relatively constant.

Another way the oral and nasal pathways differ is in the ability to protect the lungs from impurities in inhaled air. In particular, the nasal passages—being amply lined with absorbing surfaces (mucous membranes) and having many blood vessels—are more efficient than the mouth at removing water-soluble toxic gases. This difference in "scrubbing" is most pronounced when the air flows through the airways relatively slowly, as it does when a person is breathing at rest, because then the chances of contact between the contaminant and the moist mucous membrane lining are maximized.

The differences between the oral and nasal pathways have important implications for interpreting the respiratory responses (changes in measured lung function and in symptoms reported by subjects) that are observed in experiments involving the controlled inhalation of air pollutants by human volunteers. Such laboratory experiments are conducted to better understand some of the known or suspected health risks of community air pollution. Often in these experiments, to more closely simulate the real-world conditions of pollutant exposure, the subjects perform continuous or intermittent exercise on either a treadmill or an exercise bicycle.

Quantifying exposure during physical activity presents a problem, however. Researchers can measure the concentration of the pollutant in the air delivered to the subject for inhalation; but unless they account for the shift from nasal to oronasal (combined oral and nasal) breathing at elevated minute ventilation and for the attendant change in overall scrubbing efficiency, they cannot know how much of the pollutant is reaching the bronchial passages or deep lung area, the presumed site of action. To address this and other fundamental questions about oral and nasal ventilation, EPRI is sponsoring research at the University of California at Santa Barbara.

Investigators at the Institute of Environmental Stress at UCSB have devised a new exposure and ventilation measurement system by constructing special respiratory masks that separate oral and nasal airflows (Figure 2) and by developing computer programs that analyze these airflows on a breath-by-breath basis. With this system the investigators can evaluate oral and nasal ventilation in great detail. Further, they can deliver an air pollutant preferentially by the oral route, the nasal route, or both routes and determine the absolute amount that actually enters the lung.

Figure 2 This newly developed mask, fitted with dual breathing ports and low-resistance flow meters, enables airflow to be measured separately for the mouth and the nose. In tests on subjects at rest and during exercise, researchers are using the mask to study human uptake of air pollutants.

A series of tests has been completed in which normal, healthy adult subjects of both sexes were exposed to regular filtered air (no pollutant added). It was found that there are large individual differences in the time it takes to reach the crossover point and in the proportion of oral to nasal breathing at various levels of minute ventilation. It was also shown that the crossover point is reached abruptly and that the nasal component continues to contribute significantly (as much as 60%) to total minute ventilation at extremely high ventilatory volumes. The crossover point and airflow results reproduced fairly well when the same subjects were tested on separate occasions.

Experiments involving exposure to filtered air and to air containing 2.0 ppm sulfur dioxide (SO_2) are now being conducted with another set of subjects. The objectives are to monitor the proportion of oral to nasal breathing and to determine whether it influences any changes in lung function that occur. SO_2 was chosen because it is a common air pollutant that can cause constriction of the bronchial passages and symptoms of distress when inhaled in sufficient concentration. Naturally, SO_2 is of specific interest to the electric utility industry: it is a criteria pollutant (i.e., regulated by the National Ambient Air Quality Standards) and is emitted into the atmosphere from all power plants burning sulfur-containing fossil fuels.

At the first session a preliminary test is performed to find the work load (exercise rate) and minute ventilation where crossover occurs for the individual subject. At the next four sessions the subject receives, in random order, the following exposures: filtered air through the nose and mouth, air with SO_2 through the nose and mouth, air with SO_2 through the mouth, and air with SO_2 through the nose. A standard battery of lung function tests is performed before and immediately after each exposure. During each exposure the initial work load on the exercise bicycle is set at a specified level below the level shown in the preliminary test to induce crossover. The subject exercises at this work load for 30 min; afterwards the load is lowered to zero and then raised incrementally every 2 min until the breath-by-breath measurements taken through the partitioned mask indicate that the crossover point has been reached.

The results of these first exposure experiments using the unique measurement system developed at UCSB will be available in mid 1987. Plans call for extending the research to investigate the response of healthy subjects to other SO_2 concentrations and also to include asthmatic subjects. Asthmatics are an important group to study because they are generally more sensitive to the bronchoconstrictive effects of SO_2 than are people without underlying disease of the respiratory tract. In fact, recent controlled laboratory studies in which asthmatics breathed air with SO_2 concentrations typical of ambient air showed that exercise enhances bronchoconstriction. These findings have increased regulatory interest in SO_2, inasmuch as EPA is required to establish limits on criteria air pollutants to safeguard the health of sensitive populations. The findings also have motivated the UCSB researchers to use their inhalation system to clarify the roles of the oral and nasal pathways in a subject's response. It should now be possible to estimate more precisely the dose of SO_2 received and whether the ratio of oral to nasal ventilation at a known level of total ventilation is related to a person's sensitivity to the effects of SO_2.

The research being carried out under RP1225-3 is important work that will increase our understanding of basic respiratory physiology. The information obtained will help reduce uncertainty and will lead to a more critical appraisal of the scientific evidence on health risks used to support future air quality regulatory decisions—decisions that could have a major impact on utility operations. *Project Manager: Cary Young*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

RAPID: ENHANCING OPERATIONAL SAFETY AND ENGINEERING

Plant-specific system reliability studies and probabilistic risk assessments (PRAs) are used by the utilities for a variety of purposes—for example, assessing alternative system designs; modifying testing, maintenance, and operational procedures; and responding to regulatory inquiries. Further, on-site application of the PRA models promises to be valuable in assisting plant operators to maintain safe and efficient plant operation. However, PRAs require continuous update and easy access to maintain their usefulness. Computerized plant information management systems (PIMS), installed at many nuclear plants, have been limited to administrative applications. EPRI's Risk Assessment Program staff is now developing software—the reliability analysis program with in-plant data, or RAPID—to combine key features of the PIMS and PRA techniques. RAPID is expected to fulfill the promise of PRA in a wide range of engineering and operational applications.

Many nuclear power generation stations are installing upgraded on-site computers and developing computer-based PIMS. An on-site computerized information management system is also useful in supporting the data needs of many in-plant day-to-day tasks. For instance, data on equipment availability can be used to monitor the operational status of plant systems, to assess power production reliability, and to determine compliance with technical specifications, such as limiting conditions of operation. It can also be useful in PRA applications—for example, to update component reliability data, to analyze root causes of equipment failure, and to maintain configuration control of system design modifications and procedural changes. The use of PIMS, however, has been limited to assisting plant administration; its engineering and operation applications are yet to be developed.

Manually maintaining an as-built PRA, its system logic models, and component reliability data up to date is a tedious, time-consuming, manpower-intensive (and sometimes impractical) task. The voluminous information contained in a PRA and the complexity of the system logic models, as well as the lack of appropriate computer software for updating a PRA, make it difficult to keep a PRA current so that it is abreast of design modifications, procedural changes, and changing component reliability data. As a result, the usefulness of a plant-specific PRA and its system logic models may deteriorate rapidly after the study has been completed.

RAPID software

A major R&D effort is under way within EPRI's Risk Assessment Program to develop a practical engineering computer software tool for use by utilities (RP2508). The new software combines key features of PIMS with applications of system reliability analysis techniques and modern computer technology. It also helps resolve the technical difficulties of maintaining an up-to-date PIMS. More important, it aids operators in complying with technical specifications, minimizing violations, enhancing availability, and reducing the number of unplanned scrams. The study comprises two major tasks: to develop user-friendly, integrated computer software, and to demonstrate on-site the applications and value of the developed software.

The RAPID software is an aggregate of many stand-alone computer codes. It consists of three interrelated elements: an executive controller (which provides users with interface to and control of the other two elements), a data base manager (which administers data files), and applications modules (which perform specific engineering functions). RAPID's functions include both on-line and off-line activities; for example, it can monitor plant status to perform on-line applications, and it can acquire and analyze plant data to serve the needs of off-line reliability and safety analysis.

The four applications modules that have been developed are a plant status module, a technical specification evaluation module, a reliability assessment module, and a utility module. These modules provide a broad range of functions.

- Equipment status and system operability monitoring
- Dynamic plant productivity and reliability assessment
- Reliability and root cause data compilations and report generation
- Reliability-based system engineering analysis
- Technical specification evaluation and optimization
- Equipment technical specifications compliance monitoring and action tracking

Because the RAPID software has been developed for the use of all EPRI member utilities, it has to satisfy different company-specific computer operating system constraints and has to be adaptable to different computer hardware configurations. Before the development of the RAPID software was undertaken, a comprehensive study of possible software architectures determined how best to meet RAPID's requirements. As a result, two mainframe computer programs were selected to become part of RAPID: EPRI's DATATRAN (a program execution control, hierarchical data base manager, and traceability control system) and NASA's RIM (a relational data base management system) to form the basis for an executive module (EM) and a data base management module (DBM). Other features incorporated into RAPID's development include an extensive modularization at all levels of its logic hierarchy, accommodation of different types of external hardware interfaces, tools for user editing, and customization of work station screens. Figure 1 shows the RAPID software functions in a utility environment.

The purpose of EM is to assist RAPID users in making full use of information stored in RAPID. It provides RAPID users a friendly interface with the various data bases and application modules; it also provides quality assurance and quality control of internal control and applications software.

DBM supports the applications and executive modules by managing the storage and access of all data, models, and codes associated with the RAPID system. DBM provides integration and coordination of the data needs of all RAPID's modules and does so with minimum data set redundancy and maximum consistency, integrity, and quality.

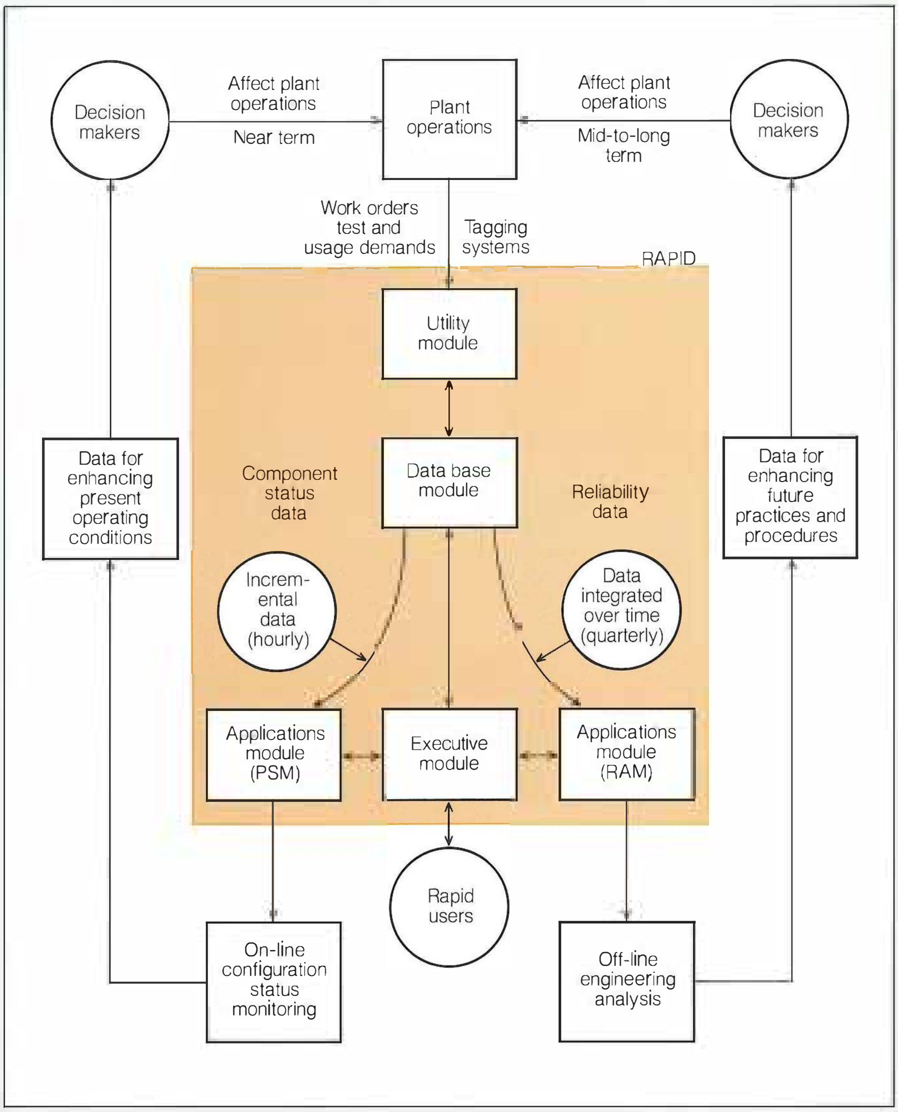
Of the application modules, the plant status module (PSM) is a computer software tool to aid plant management, operations, and maintenance personnel in monitoring and assessing the operational status of their nuclear power plant. PSM is a state-of-the-art development. It is controlled and supported by the EM and DBM and uses systems analysis techniques to monitor plant status. The primary functions of PSM are as follows.

- Maintain component availability status information
- Determine system operability status
- Assess power production level reliability and safety systems availability
- Compile equipment failure and repair history and maintenance records
- Monitor technical specification compliance, track timing, and actions statements
- Prepare event record and shift logs

System analysis techniques play an essential role in the efficient performance of PSM functions and the achievement of the fast response required in an operational environment. The system logic models and plant-level models are used to derive the relationships among the equipment availability status, plant operation mode, plant power level, and intended PSM functions.

The reliability assessment module (RAM) was developed to computerize a broad range of basic probabilistic system analysis functions. It uses the general functions of EM and DBM to automate standard analytic routines involving data, models, and computer codes. Thus, RAM software, in contrast to PSM, enables RAPID/RAM users to access a set of prescribed computerized procedures for performing reliability analysis tasks, such as using EPRI's WAMBAM or Sandia's SETS codes to quantify a fault tree. RAM software performs three primary functions: it conducts topical system modeling and data analyses; it maintains system models and data; and it ensures traceability and quality control.

Figure 1 Applications of RAPID software at a nuclear utility. The on-line activities address operational assistance; the off-line tasks are basic reliability engineering activities.



EM and DBM, together with RAM software, provide a computerized environment for maintaining the data, models, and documentation required to keep a complex and voluminous PRA up to date. Other benefits of using RAM include enhancement of the analyst's productivity and the coherent use of data.

The technical specification evaluation module (TSEM) is special task-oriented software. It evaluates systems and PRA event sequences to determine the sensitivity of risk or of system availability to technical specifications and the requirements of limiting conditions of operation or to equipment status changes. To perform this function, TSEM is supported by EM and DBM with system models and PRA event sequences, as well as by component unavailability models and data. TSEM manages input and output data for executing the technical specification evaluating codes, such as EPRI's SOCRATES or NRC's FRANTIC III.

The utility module (UM) provides the interface between RAPID and automated or manual PIMS. It is controlled from EM to acquire failure, demand, and repair data from a PIMS and to update this information in DBM.

RAPID demonstrations

RAPID/PSM and RAPID/RAM–UM are being tested and demonstrated at two member utilities; the development of the RAPID/TSEM software has just started.

PSM was developed under a cooperative agreement with General Public Utilities Nuclear Corp. (GPUN). The software was developed to be generic to such an extent that it can be operated on a wide variety of computer hardware. Currently, it is installed on an IBM Sierra mainframe and uses a video display terminal as a work station. GPUN's Oyster Creek nuclear generation station plant-specific information is being used in the PSM data base for testing the PSM software package.

The PSM version being operated at Oyster Creek has all the functions described above. Forty-seven GO system models, consisting of 5400 components, have been constructed. These models have been integrated into a plant-level model to perform PSM functions.

The input to PSM is only a list of current out-of-service components. PSM software uses this input to evaluate the plant system logic models and to determine the operational status of the plant, its systems, and their trains.

Operators can also postulate out-of-service components for "what if" inquiries. The resultant plant operational status information is then used to monitor technical specification compliance, to track time-action statements, and to identify any technical specification conflicts resulting from the intersystem dependencies. In the plant health calculation, the software assesses the probability of continued power operation at various established power levels of the current plant configuration and the availability of safety systems to function when required. RAPID/PSM is in its final phase of software testing and data verification.

RAPID/RAM–UM software was developed under a cooperative agreement with Arizona Public Service Co.'s Arizona Nuclear Power Project (ANPP). The principal purpose is to demonstrate that keeping a Level-1 PRA study up to date can be a reality without imposing an undue burden on support staff. RAM software creates and maintains a series of model files that contain information on the model logic, data for model quantification, model cut sets, and other information necessary for maintenance of the models. It verifies the model input data, edits the model, and prepares a new input deck to execute. RAM provides updated results and models to the data base manager for automatic documentation, update, and quality assurance.

RAPID/UM software acquires data from the plant information system, if any, and when necessary, converts it for use in RAPID. The interface with the plant system is flexible and is adaptable to most plants. RAPID/UM is being used to extract the data from the on-site PIMS at ANPP's Palo Verde plant.

The ANPP engineering staff is using RAM and UM software for developing systems fault tree models and event tree sequences to describe a small loss-of-coolant accident, constructing several GO system models for the plant availability study, and compiling plant-specific data from the station information management system. Currently, the software is installed on an IBM 3084 mainframe computer using the MVS/XA operating system; IBM PC–AT microcomputers are used as the engineering work stations. Both RAM and UM software are operational at the project's computer service center. The functions of RAPID/RAM and RAPID/UM are being tested and debugged as these activities progress.

The general conclusion from the work to date is that the combination of data base management capability with an executive controller and reliability applications packages can be made to work effectively. It promises considerable on-line and off-line benefits. The main tasks ahead include demonstrating a capability to incorporate a variety of proprietary software used by utilities to address reliability issues and discovering how to integrate this new capability into the operational life of a plant.

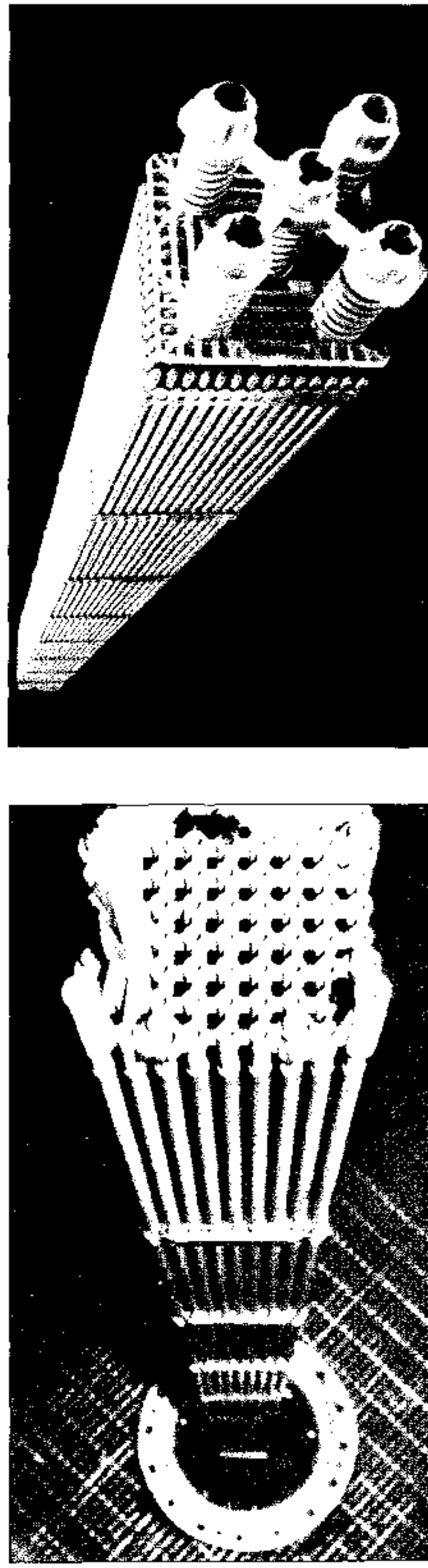
The first of these tasks should not prove too difficult because the DATATRAN executive was designed to encompass other applications codes. The most challenging task will be the second—getting a software tool such as PSM accepted by operations personnel and having it used routinely with adequate accuracy.

We believe RAPID/RAM has promise to be an efficient means for maintaining a PRA and for conducting and documenting the increasing number of reliability and system logic analyses being used in today's nuclear power plants. To accomplish these objectives, extended trials are envisaged at several utilities during 1987 and 1988. *Project Manager: Boyer Chu*

ESCORE: A STEADY-STATE CORE RELOAD EVALUATOR

Predictions of nuclear fuel performance are important considerations in the design and evaluation of fuel assemblies, in the licensing of fuel reloads, and in reactor operations under various conditions. ESCORE is a FORTRAN computer code that calculates the steady-state response of light water reactor (LWR) fuel rods during long-term irradiation to burnups exceeding 50 GWd/tU. ESCORE was developed and tuned to give best-estimate predictions for fuel designed to operate in both boiling water reactors (BWRs) and pressurized water reactors (PWRs). The code calculates the thermal and mechanical responses of a fuel rod as functions of time-dependent rod power, fast-neutron flux, and coolant operating conditons.

Figure 2 LWR fuel assemblies containing individual fuel rods approximately 12 ft (3.66 m) in length and 0.4 in (1.02 cm) in diameter. Combustion Engineering, Inc., PWR assembly (top); Exxon Nuclear Co. 9 × 9 BWR assembly (bottom).



Nuclear fuel assemblies are made up of square arrays of rods, typically 12 ft (3.66 m) long and 0.4 in (1.02 cm) in diameter, that contain UO_2 pellets (Figure 2). During operation, nuclear fission and the resultant temperature distribution within the rod cause significant changes in the properties of the fuel, both instantaneously and with exposure. Because these changes affect the thermal and mechanical response of the fuel, they must be modeled so that the performance of the fuel is adequately predicted. To this end, ESCORE can be used to verify compliance with mechanical design and licensing criteria, such as internal pin pressure and transient strain, and to provide input to creep-collapse analyses. ESCORE can also provide initial-condition fuel characteristics for transient analyses and fuel thermal-limit calculations as part of a safety analysis, and it can be used in establishing technical specifications for permissible linear heat rates, peaking factors, and other limits that preclude fuel damage.

ESCORE analyzes a single fuel rod composed of Zircaloy-encapsulated, cylindrical pellets of solid or annular UO_2 fuel. The fuel rod is assumed to consist of discrete axial segments for which independent radial thermal equilibrium calculations are performed. It is further assumed that there is complete mixing of the free gases within the fuel rod for integrated, whole-rod predictions; therefore, the converged results for each axial segment are coupled to those of other segments.

Models in ESCORE describe the fuel and cladding behavior as it is influenced by the irradiation history of the fuel assemblies. Fuel models include a steady-state radial temperature predictor, including flux or power depression, thermal expansion, relocation, densification, swelling, fission-gas production and release, and elastic and nonelastic deformation. Cladding models include a steady-state radial temperature predictor with power deposition, thermal and elastic expansion, creep, and growth.

The fuel pellet is assumed to be a right circular cylinder that responds to thermal and fission-induced volumetric changes. The Zircaloy cladding elastically and plastically conforms to the fuel pellet for computed conditions of the pellet-cladding contact. Before contact, the cladding is assumed to be freestanding. Rod internal pressure is a computed function of the fill-gas and released fission-gas content and of the rod internal void volume open to the free gas. The fuel temperature depends on the fuel-to-cladding gap conductance, computed as a function of the gap-gas conductivity and open-gap size or contact load.

ESCORE has been developed to give best-estimate fuel performance predictions for fuel designed to operate in both BWRs and PWRs. In some cases, discrete models were developed to accommodate the different thermal-hydraulic conditions in these two reactor designs. The tuning and verification data sets included fuel designed by the major U.S. fuel vendors and used in various reactor cores.

One of the most important and difficult estimates of fuel rod behavior is that of the radial temperature distribution. These estimates are important in subsequent safety analyses and because of the effect that predicted temperatures have on other phenomena, such as fission-gas release and internal fuel rod pressure. Fuel temperatures are difficult to predict because of the complicated phenomena that occur as the rods are irradiated and that influence thermal properties. The thermal properties thus affected, for example, are fuel relocation, fuel conductivity changes, fuel swelling, and gap-conductivity poisoning by fission gases. In addition, there are significant uncertainties in the data available for benchmarking the thermal models.

ESCORE-predicted fuel centerline temperatures have been shown to compare favorably, within acceptable ranges of deviation, with those measured on a large number of specially instrumented fuel rods. Moreover, the scatter of the data points in this comparison was not a function of independent variables, such as power or burnup.

The ESCORE code has been tuned and benchmarked to an extensive data base. Data comparisons were performed with 156 fuel rods selected as being typical of the data base. In assembling the data base, rods that were well characterized with respect to mechanical design and irradiation history were chosen. A mixture of fuel rods typical of both PWR and BWR designs was included.

The irradiation histories of these rods varied widely. Many had irradiation histories typical of rods in commercial reactors; others were irradiated in commercial reactors and then power-ramped in test reactors. The experimentally measured parameters selected for comparison with the ESCORE predictions were fuel temperature, fission-gas release, fuel rod internal void volume, cladding creep, and cladding corrosion.

The input and output formats for ESCORE were designed to facilitate the code's use. EPRI's Utility Support Group was especially influential in the design of the input and output formats, tailoring them to respond to general and specific utility needs.

Version 1A of ESCORE has been released by the Electric Power Software Center in both IBM and CDC versions. ESCORE has been built and distributed under QA plans. Several EPRI member utilities, part of the Utility Group for Regulatory Action, are going to submit the code to NRC for its review. A three-volume set of code manuals (NP-4492-CCMP) has been issued, and a topical report will be published in 1987. *Program Manager: David Franklin*

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Advanced Power Systems		
Studies of Long-Lived Sodium-Sulfur Cell (RP128-18)	$147,700 12 months	Ceramatec, Inc./ *R. Weaver*
Planar Solid Oxide Fuel Cell Development (RP1676-9)	$161,000 10 months	Ztek Corp./ *R. Goldstein*
New Concepts for the Control and Operation of a Combined-Cycle Power Plant (RP2101-10)	$54,900 9 months	General Electric Co./ *G. Quentin*
Application of Optical Fiber Thermometry to a Combustion Turbine (RP2102-20)	$223,300 17 months	Accufiber, Inc./ *G. Quentin*
IGCC Site-Specific Study (RP2773-4)	$377,000 14 months	Virginia Power/ *A. Lewis*
Power-Conditioning System for the SCE Chino Battery Energy Storage System (RP2870-2)	$1,868,200 15 months	General Electric Co./ *D. Morris*
Power-Conditioning-System Engineering Support and Engineer-of-Record Services (RP2870-3)	$268,200 44 months	United Engineers & Constructors, Inc./ *D. Morris*
Coal Combustion Systems		
Monitoring of Startup and Operation of Intermountain Baghouse (RP1129-14)	$329,900 17 months	Southern Research Institute/*W. Piulle*
Cycling Study at Potomac River Station (RP1184-21)	$443,200 23 months	Potomac Electric Power Co./*G. Poe*
Boiler R&D for Advanced Fossil Fuel Power Plants (RP1403-19)	$1,314,500 38 months	Foster Wheeler Development Corp./*W. Bakker*
Boiler Tube Corrosion Failure in Waterwalls and Economizers (RP1890-5)	$2,786,300 30 months	Ontario Hydro/ *B. Dooley*
Overfire-Air NO_x Control: Design and Operating Guidelines (RP2154-13)	$35,200 6 months	Riley Stoker Corp./ *D. Eskinazi*
Operational Testing Agreement for Colorado-Ute Nucla Circulating-Fluidized-Bed Demonstration (RP2683-1)	$10,000,000 36 months	Colorado-Ute Electric Association, Inc./ *C. Lawrence*
Software Development for Colorado-Ute AFBC Demonstration (RP2683-6)	$233,600 12 months	Systems Control, Inc./ *J. Stallings*
Electrical Systems		
Demonstration and Evaluation of Transmission Line Digital Protective Relaying Devices (RP1359-14)	$675,400 24 months	Westinghouse Electric Corp./*S. Wright*
Insulation Coordination of AC and DC Stations (RP2323-3)	$54,600 5 months	Westinghouse Electric Corp./*S. Wright*
Insulation Coordination of AC and DC Stations (RP2323-4)	$87,000 12 months	West Virginia University/ *R. Kubik*
Parameter Identification Data Acquisition System (RP2328-3)	$401,000 28 months	General Electric Co./ *J. Edmonds*
Data Base Management Systems for Power System Planning: Phase 2 (RP2668-2)	$339,000 16 months	Carlsen and Fink Associates, Inc./ *J. Lamont*
Advanced Primary Transducers (RP2734-1)	$152,800 14 months	McGraw-Edison Power Systems/*H. Songster*
Advanced Primary Transducers (RP2734-2)	$118,000 7 months	Westinghouse Electric Corp./*H. Songster*
Energy Management and Utilization		
Development of an Optimal Controller for Commercial Cool Storage (RP2732-4)	$536,900 30 months	Honeywell, Inc./ *R. Wendland*
Evaluation of Improved Dual-Fuel Heat Pump (RP2868-3)	$38,000 6 months	ETL Testing Laboratories, Inc./*C. Hiller*
Commercial Food Service and Restaurant Data Analysis and Synthesis (RP2890-1)	$151,300 6 months	Hart, McMurphy & Parks, Inc./*G. Purcell*
Assessment of Electrotechnologies in Drying and Process Heating (RP2893-3)	$72,900 12 months	Thermo Energy Corp./ *A. Karp*
Modeling of Flow Processes and Tube Erosion in Fluidized-Bed Combustion (RP8006-3)	$50,000 4 months	Argonne National Laboratory/*J. Stringer*
Environment		
Case-Control Study of Electromagnetic Fields and Childhood Leukemia (RP799-24)	$343,900 23 months	University of Southern California/*R. Black*
Operational Evaluation Network (OEN) Project (RP2434-4)	$13,493,000 56 months	ERT/*G. Hilst*
Nuclear Power		
Analytic Support for Large-Scale Experimental Tests (RP1227-6)	$99,100 13 months	Jaycor/*J. Sursock*
Laboratory Evaluations of Cobalt-Free Hard-Facing Alloys (RP1935-11)	$181,000 26 months	Kraftwerk Union/ *H. Ocken*
Plant Decontamination Method Review Update (RP2296-15)	$35,000 9 months	Applied Radiological Control, Inc./*C. Wood*
Preliminary Conceptual Design Study for a Small LWR (RP2660-7)	$300,000 18 months	Westinghouse Electric Corp./*W. Sugnet*
Engineering Model for Fatigue Ratcheting (RP2689-4)	$49,900 8 months	S. Levy, Inc./*S. Tagart*
Cooperative Spent-Fuel R&D Program (RP2717-4)	$100,000 6 months	Rochester Gas & Electric Corp./*R. Williams*
Fuel-Cycle Scoping Capability Development (RP2721-2)	$147,200 15 months	S. Levy, Inc./*O. Ozer*

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.

ADVANCED POWER SYSTEMS

Technology Assessments of Advanced Power Generation Systems II: Kalina Bottoming Cycle
AP-4681 Final Report (RP2528-4); $25
Contractor: Mechanical Technology, Inc.
EPRI Project Manager: A. Cohn

Proceedings: Workshop on Prospects and Requirements for Geographic Expansion of Wind Power Usage
AP-4794 Proceedings (RP1996-20); $25
Contractor: Steitz & Associates
EPRI Project Manager: F. Goodman

Screening Evaluation of Advanced Power Cycles
AP-4826 Final Report (RP2477-1); $40
Contractor: Fluor Technology, Inc.
EPRI Project Manager: B. Louks

Coproduction of Carbon Dioxide and Electricity
AP-4827 Final Report (RP2221-16); $32.50
Contractor: Fluor Technology, Inc.
EPRI Project Manager: B. Louks

Very Small (Approximately 500 kW) Low-Cost Gas-Fired Power Plants
AP-4837 Final Report (RP2528-3); $32.50
Contractor: Utah Power & Light Co.
EPRI Project Manager: A. Cohn

Dynamic Operating Benefits of Energy Storage
AP-4875 Final Report (RP1745-13); $25
Contractor: Decision Focus, Inc.
EPRI Project Manager: T. Yau

Ocean Energy Technologies: State of the Art
AP-4921 Final Report (RP1348-28); $32.50
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: S. Feher

COAL COMBUSTION SYSTEMS

Economic Evaluation of FGD Systems: NOXSO and SOXAL Sodium-Based Processes and Four Additional Calcium-Based Processes
CS-3342 Final Report (RP1610-2); Vol. 5, $55
Contractor: Stearns Catalytic Corp.
EPRI Project Manager: R. Moser

Dissimilar-Weld Failure Analysis and Development Program: Accelerated Discriminatory Tests
CS-4252 Final Report (RP1874-1); Vol. 3, $40
Contractor: Metal Properties Council, Inc.
EPRI Project Manager: R. Viswanathan

Generic Guidelines for the Life Extension of Fossil Fuel Power Plants
CS-4778 Final Report (RP2596-1); $1000
Contractors: Daedalus Associates, Inc.; Delian Corp.
EPRI Project Managers: B. Dooley, J. Byron

In Situ Vitrification of PCB-Contaminated Soils
CS-4839 Final Report (RP1263-24); $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Managers: M. McLearn, R. Komai

Spectral Flame Analyzer for Burner Control in Fossil Fuel Boilers
CS-4844 Final Report (RP1681-2); $25
Contractor: Thermo Electron Corp.
EPRI Project Manager: R. Leyse

Limestone Dissolution Studies
CS-4845 Final Report (RP1031-4); $40
Contractor: Radian Corp.
EPRI Project Managers: D. Stewart, R. Moser

Field Evaluation of the S-Cubed Model PCBA-102 PCB Analyzer
CS-4846 Final Report (RP1263-23); $25
Contractor: Brown and Caldwell
EPRI Project Managers: R. Komai, M. McLearn

Gas-Cleaning Technology for High-Temperature, High-Pressure Gas Streams: 1984 Annual Report
CS-4859 Interim Report (RP1336-1); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: S. Drenker, O. Tassicker

Alternative Combustion Turbine Designs and Cleanup Systems for Pressurized-Fluidized-Bed Combustion Power Plants
CS-4860 Final Report (RP1336-1); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: S. Drenker

Calcium Sulfite and Calcium Sulfate Crystallization
CS-4861 Final Report (RP1031-3); Vol. 1, $25; Vol. 2, $25
Contractor: University of Arizona
EPRI Project Managers: D. Stewart, R. Moser

Proceedings: Municipal Solid Waste as a Utility Fuel
CS-4900-SR Proceedings; $47.50
EPRI Project Manager: C. McGowin

Proceedings: Sixth Symposium on the Transfer and Utilization of Particulate Control Technology
CS-4918 Proceedings (RP1835-12); Vol. 1, $55; Vol. 2, $70; Vol. 3, $55
Contractor: Radian Corp.
EPRI Project Manager: R. Altman

ELECTRICAL SYSTEMS

Improved Motors for Utility Applications
EL-4286 Final Report (RP1763-2); Vol. 2, $47.50; Vol. 6, $25; Vol. 7, $25
Contractor: General Electric Co.
EPRI Project Manager: D. Sharma

Electromagnetic Transients Program (EMTP) Application Guide
EL-4650 Final Report (RP2149-1); $55
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Mitsche

Electromagnetic Transients Program Workbook
EL-4651 Final Report (RP2149-6); $40
Contractor: University of Wisconsin at Madison
EPRI Project Manager: J. Mitsche

Unified Active and Reactive Power Modulation of HVDC Systems: Large-Signal and Distributed Small-Signal Control
EL-4822 Final Report (RP1426-4); $47.50
Contractor: General Electric Co.
EPRI Project Manager: S. Wright

Power System Planning and Operations: Voltage-VAR Projects—Seminar Proceedings
EL-4863 Proceedings (RP1530, RP1712, RP1724, RP2109, RP2148); $25
Contractors: Power Technologies; Scientific Systems, Inc.; ESCA Corp.; Carlsen & Fink Associates, Inc.
EPRI Project Manager: J. Lamont

Rotor-Mounted Monitoring System for Hydroelectric Generators
EL-4876 Final Report (RP2591-2); $25
Contractor: Spectra Technology, Inc.
EPRI Project Manager: J. Edmonds

Explosive Fabrication of Multilayer Damper Shield
EL-4909 Final Report (RP1473-10); $32.50
Contractor: Battelle, Columbus Laboratories
EPRI Project Manager: J. Edmonds

300-MVA Superconducting Generator Documentation: Heat Transfer to Helium Fluid Under High-Speed Rotation
EL-4910 Final Report (RP1473); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Edmonds

ENERGY MANAGEMENT AND UTILIZATION

Heat Pumps in Evaporation Processes
EM-4693 Final Report (RP2220-2); $55
Contractor: Union Carbide Corp.
EPRI Project Manager: A. Karp

Data Collection and Estimation for Multiple-Account and Mixed-Use Facilities: A Monograph From the COMSURV Project
EM-4884 Final Report (RP1216-9); $25
Contractor: Applied Management Sciences, Inc.
EPRI Project Manager: L. Lewis

Field Validation of Mail Surveys: A Monograph From the COMSURV Project
EM-4885 Final Report (RP1216-9); $32.50
Contractor: Applied Management Sciences, Inc.
EPRI Project Managers: A. Faruqui, L. Lewis

Scoping Study of Intelligent Data Bases: Potential Applications of Artificial Intelligence Techniques in a Demand-Side Management Data Base
EM-4896 Final Report (RP2381-12); $25
Contractor: Carnegie Mellon University
EPRI Project Manager: D. Hu

Resistance Heating of Nonmetals: State-of-the-Art Assessment
EM-4915 Final Report (RP2613-3); $25
Contractor: Battelle, Columbus Division
EPRI Project Manager: L. Harry

COGEN3: Cogeneration Analysis Software (Version 1.3, User's Guide)
EM-4923-CCM Computer Code Manual (RP1538-2); $40
Contractor: Mathtech, Inc.
EPRI Project Manager: D. Hu

ENVIRONMENT

Priority Service: Unbundling the Quality Attributes of Electric Power
EA-4851 Interim Report (RP2440-2); $32.50
Contractor: Pricing Strategy Associates
EPRI Project Manager: H. Chao

EPRI Water Supply Computerized Information Directory
EA-4871 Final Report (RP762, RP1010, RP1603); $32.50
Contractor: University of Arizona
EPRI Project Manager: E. Altouney

Capital Budgeting for Utilities: The Revenue Requirements Method
EA-4879 Final Report (RP1920-3-1); $32.50
Contractor: Charles River Associates, Inc.
EPRI Project Manager: S. Chapel

Paleoecological Investigation of Recent Lake Acidification: Methods and Project Description
EA-4906 Interim Report (RP2174-10); $40
Contractor: Indiana University
EPRI Project Manager: R. Goldstein

Application of the Ecosystem Assessment Model to Lake Norman, a Cooling Lake in North Carolina
EA-4907 Final Report (RP1488-2); $32.50
Contractor: Tetra Tech, Inc.
EPRI Project Managers: R. Kawaratani, J. Mattice

NUCLEAR POWER

Evaluation of BWR Top-Guide Integrity
NP-4767 Final Report (RP2680-2); $32.50
Contractors: Structural Integrity Associates, Inc.; Anatech International Corp.
EPRI Project Manager: T. Griesbach

Development of Cobalt-Free Hard-Facing Alloys for Nuclear Applications: 1985 Progress
NP-4775 Interim Report (RP1935-5); $25
Contractor: AMAX Materials Research Center
EPRI Project Manager: H. Ocken

Improved Ultrasonic Inspection Techniques for Creviced Safe Ends
NP-4796 Final Report (RPT301-14); $25
Contractor: General Electric Co.
EPRI Project Manager: M. Avioli

Evaluation of Environmental Effects on Intergranular Attack of Alloy 600
NP-4802 Final Report (RPS302-9); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: P. Paine, Y. Solomon

The Effects of Target Hardness on the Structural Design of Concrete Storage Pads for Spent-Fuel Casks
NP-4830 Final Report (RP2717-3); $25
Contractor: Anatech International Corp.
EPRI Project Manager: R. Williams

Nuclear Plant Piping Criteria and Construction Costs
NP-4843M Final Report (RP2513-1); $32.50
Contractor: Teledyne Engineering Services
EPRI Project Manager: G. Sliter

Modeling of Two-Phase Flow During Bottom Reflooding in PWRs
NP-4853 Final Report (RP959-6); $32.50
Contractor: Science Applications International Corp.
EPRI Project Managers: M. Divakaruni, R. Duffey

Scaling of Two-Phase Flow During Natural Circulation in a PWR Hot Leg
NP-4854 Final Report (RP2393-1); $25
Contractor: Creare R&D, Inc.
EPRI Project Managers: M. Divakaruni, J. Sursock

Survey of the Literature Applicable to Two-Phase Natural Circulation Flows in the Hot Leg of a PWR
NP-4855 Final Report (RP2393-1); $32.50
Contractor: Creare R&D, Inc.
EPRI Project Managers: M. Divakaruni, J. Sursock

Graphic Display Development Methodology
NP-4874 Final Report (RP2347-14); Vol. 1, $62.50; Vol. 2, $32.50
Contractor: Operations Engineering, Inc.
EPRI Project Manager: D. Cain

Evaluation of Flawed-Pipe Experiments
NP-4883M Final Report (RP2457-8); $25
Contractor: Novetech Corp.
EPRI Project Manager: D. Norris

TMI-2 Sludge Separation and Packaging Analyses and Conceptual Design
NP-4886 Final Report (RP2012-12); $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: R. Lambert

The Castor-V/21 PWR Spent-Fuel Storage Cask: Testing and Analyses
NP-4887 Interim Report (RP2406-4); $40
Contractors: Virginia Power; Pacific Northwest Laboratory; EG&G, Idaho National Engineering Laboratory
EPRI Project Manager: R. Lambert

Investigation of ASME Code, Section III, Subsection NB: Suggested Revisions
NP-4888 Final Report (RP1757-47); $25
Contractor: Reedy Associates, Inc.
EPRI Project Manager: S. Tagart

Investigation of Advanced Acoustic and Optical Nondestructive Evaluation Techniques
NP-4897 Final Report (RP606-7); $32.50
Contractor: Sigma Research, Inc.
EPRI Project Manager: M. Behravesh

Evaluation of PWR Tubesheet Crevice-Flushing Approaches
NP-4898 Final Report (RPS302-21); $32.50
Contractor: NWT Corp.
EPRI Project Manager: L. Williams

Calvert Cliffs Unit 1 Tube Examination
NP-4904 Final Report (RPS304-10); $25
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: P. Paine

Review of Records Requirements Related to LWR Life Extension
NP-4926 Final Report (RP2643-3); $32.50
Contractor: Grove Engineering, Inc.
EPRI Project Manager: M. Lapides

PLANNING AND EVALUATION

Managing Technology in Mature Industries
P-4872 Final Report (RP5005); $25
Contractor: Arthur D. Little, Inc.
EPRI Project Manager: K. Miller

R&D STAFF

Grain Boundary Composition and Intergranular Fracture of Steels: Evaluation of Segregation and Its Synergism With Stress Corrosion and Hydrogen Embrittlement
RD-3859 Final Report (RP2257-1); Vol. 2, $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: R. Viswanathan

Mathematical Modeling of Electrochemical Conditions Within a Stress Corrosion Crack
RD-4877 Final Report (RP2258-2); $25
Contractor: Battelle, Columbus Division
EPRI Project Manager: B. Syrett

New Computer Software

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ATHOS3: Thermal-Hydraulic Analysis of Steam Generators
Version 1.0 (CDC, IBM); NP-4604-CCM
Contractor: CHAM of North America, Inc.
EPRI Project Manager: G. Srikantiah

CITOU: Commercial-Industrial Time-of-Use Response Model
Version 1.0 (IBM PC); EA-4206
Contractor: Research Triangle Institute
EPRI Project Manager: P. Hanser

COGEN3: Design, Costing, and Economic Optimization of Cogeneration Projects
Version 1.3 (IBM CMS, IBM MVS)
Contractor: Mathtech, Inc.
EPRI Project Manager: D. Hu

EMTP: Electromagnetic Transients Program
Version 1.0 (APOLLO, IBM CMS, IBM MVS, PRIME, VAX); EL-4541, EL-4652
Contractor: EMTP Development Coordination Group
EPRI Project Manager: J. Mitsche

RAMAS: Risk Analysis and Management Alternatives System
Version 3.1 (IBM PC)
Contractor: Applied Biomathematics, Inc.
EPRI Project Manager: A. Silvers

RETRAN-02: One-Dimensional Transient Thermal-Hydraulic Analysis
Version MOD004 (CDC, IBM); NP-1850
Contractor: Energy, Inc.
EPRI Project Manager: L. Agee

TELPLAN: TELPLAN Integrated Utility Planning Model
Version 2.0 (IBM, PRIME); EA-2581
Contractor: TERA Corp.
EPRI Project Manager: D. Geraghty

CALENDAR

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

MARCH

12–13
Seminar: Maintaining Equipment Qualification
Boston, Massachusetts
Contact: Robert Kubik (415) 855-8905

23–26
1987 Joint Symposium: Stationary NO_x Control
New Orleans, Louisiana
Contact: David Eskinazi (415) 855-2918

APRIL

14–16
14th Annual Conference and Exposition: Energy Technology
Washington, D.C.
Contact: Karen Noyes (301) 251-9250

JUNE

9–10
Computerized Cost Estimating: Flue Gas Desulfurization Retrofit
Denver, Colorado
Contact: Robert Moser (415) 855-2277

AUGUST

25–26
Symposium: Power Plant Valves
Kansas City, Missouri
Contact: Stanley Pace (415) 855-2826

OCTOBER

6–9
1987 Seminar: PCBs
Kansas City, Missouri
Contact: Gilbert Addis (415) 855-2286

13–15
Conference: Effects of Coal Quality on Power Plants
Atlanta, Georgia
Contact: Arun Mehta (415) 855-2895

28–30
Fish Protection at Steam and Hydro Power Plants
San Francisco, California
Contact: Wayne Micheletti (415) 855-2469

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