# Perspective on Greenhouse Issues

ELECTRIC POWER RESEARCH INSTITUTE

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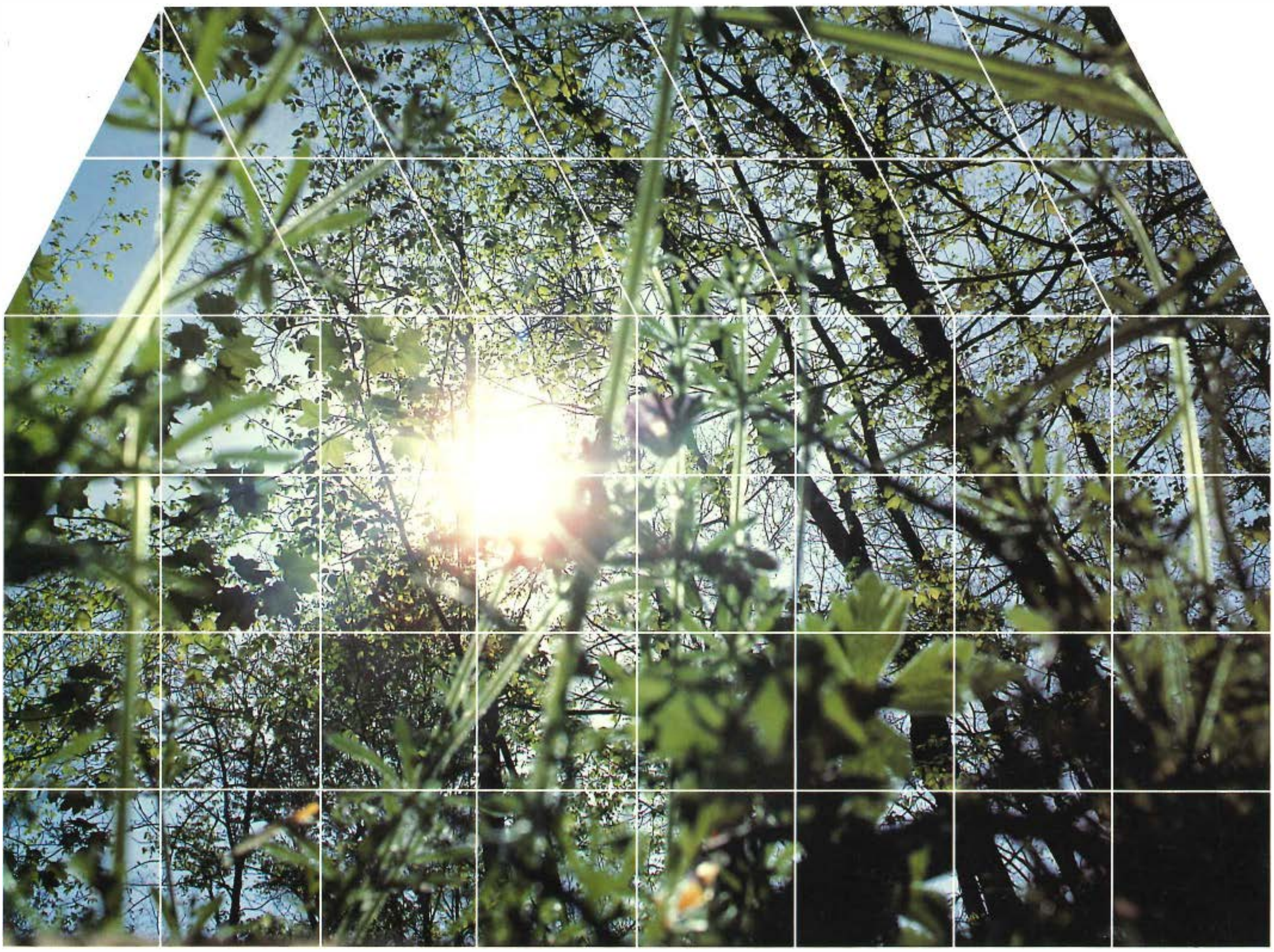

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Cover: Scientists and policymakers fear that global warming from atmospheric accumulation of greenhouse gases may become the most problematic environmental issue civilization has ever faced. (Photo by Ron May)

# Coping With Climate Change

There is growing consensus in the scientific community that the greenhouse effect is real. Combustion-generated carbon dioxide may indeed cause significant warming of the atmosphere over the next half-century, and other heat-absorbing gases are expected to hasten the process. The environmental consequences of such global warming are not well understood but are hypothesized to include changes in aridity, agricultural practice, forest growth, and sea level rise. At current rates of worldwide fossil fuel use, there is a possibility that such changes will disrupt the biosphere as we know it and force regions or nations to adapt to new climate patterns. Even more disconcerting is the possibility of destabilization of the earth's entire weather system, resulting in conditions that are not currently forecastable. These issues have raised the public awareness of global warming from the scientific workplace to the realm of international public policy.

The increasing weight of evidence of warming, the timing required for modifications in energy use, and the difficulty in resolving sociopolitical implications have also made this issue much more visible to the various energy suppliers of the world. Meeting the worldwide requirements for energy consumption by shifting away from fossil fuel use is a prospect that seems impractical, given the heterogeneity of global economics and society's apprehension about alternatives, such as nuclear power. Thus, adaptability becomes the watchword in coping with the possibility of climate change. But adaptability will depend on the severity and rate of change of possible effects, and neither of these factors is predictable with any degree of certainty.

The electric utility industry finds itself in a peculiar position in dealing with the potential of global warming. Utilities are said to be responsible, in some degree, for the problem because they burn fossil fuels; but at the same time, electricity will be crucial to effective adaptation to projected changes. Thus the industry's involvement includes not only the question of emission reduction but also the incorporation of climate change in its long-term planning for electricity needs. EPRI has expanded its research program to develop an improved scientific basis for deciding such courses of action.

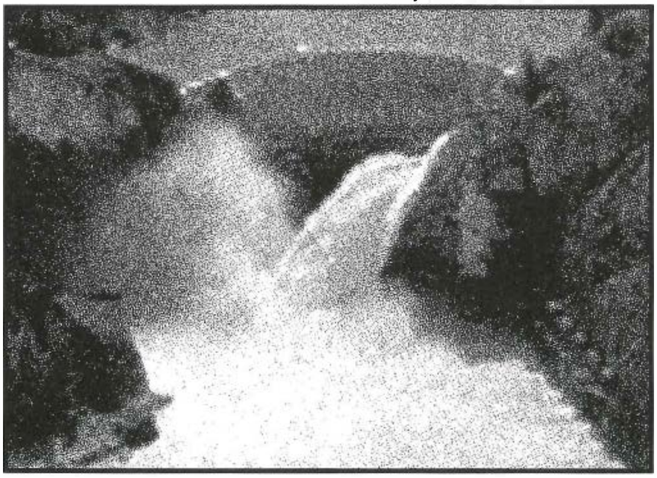
Since the U. Sgovernment annually invests more than $100 million in climate research, our program must be highly selective in scope and contribution. We have elected to investigate three important areas: the key aspects of biologic interactions involving ocean and plant photosynthesis; the significance of a greenhouse gas, nitrous oxide, whose sources are emissions from power plants as well as natural causes; and the logistic and economic analysis of planning for electricity needs, should climate warming occur. By carrying out this program and closely monitoring the work of others, EPRI will be in a position to assist its members in creatively coping with climate as an important component of their environmental decision making.

G. M. Hidy
George M. Hidy
Vice President, Environment Division

## RESEARCH UPDATE







## DEPARTMENTS

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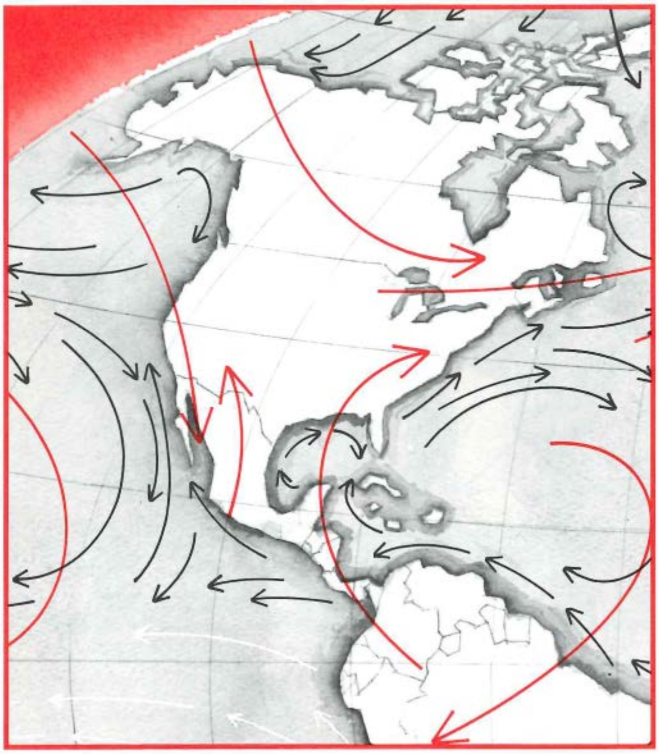
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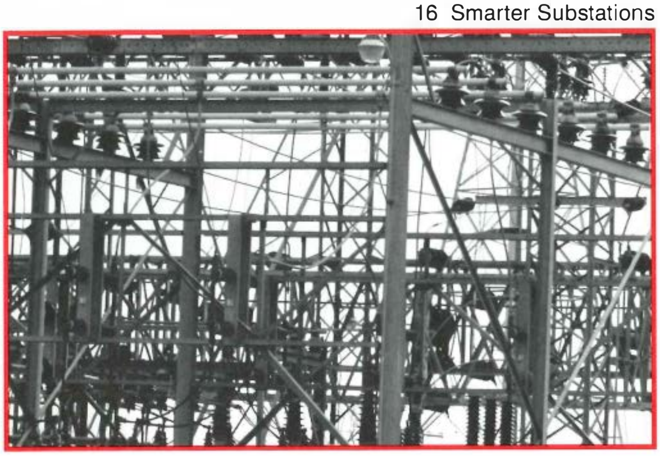
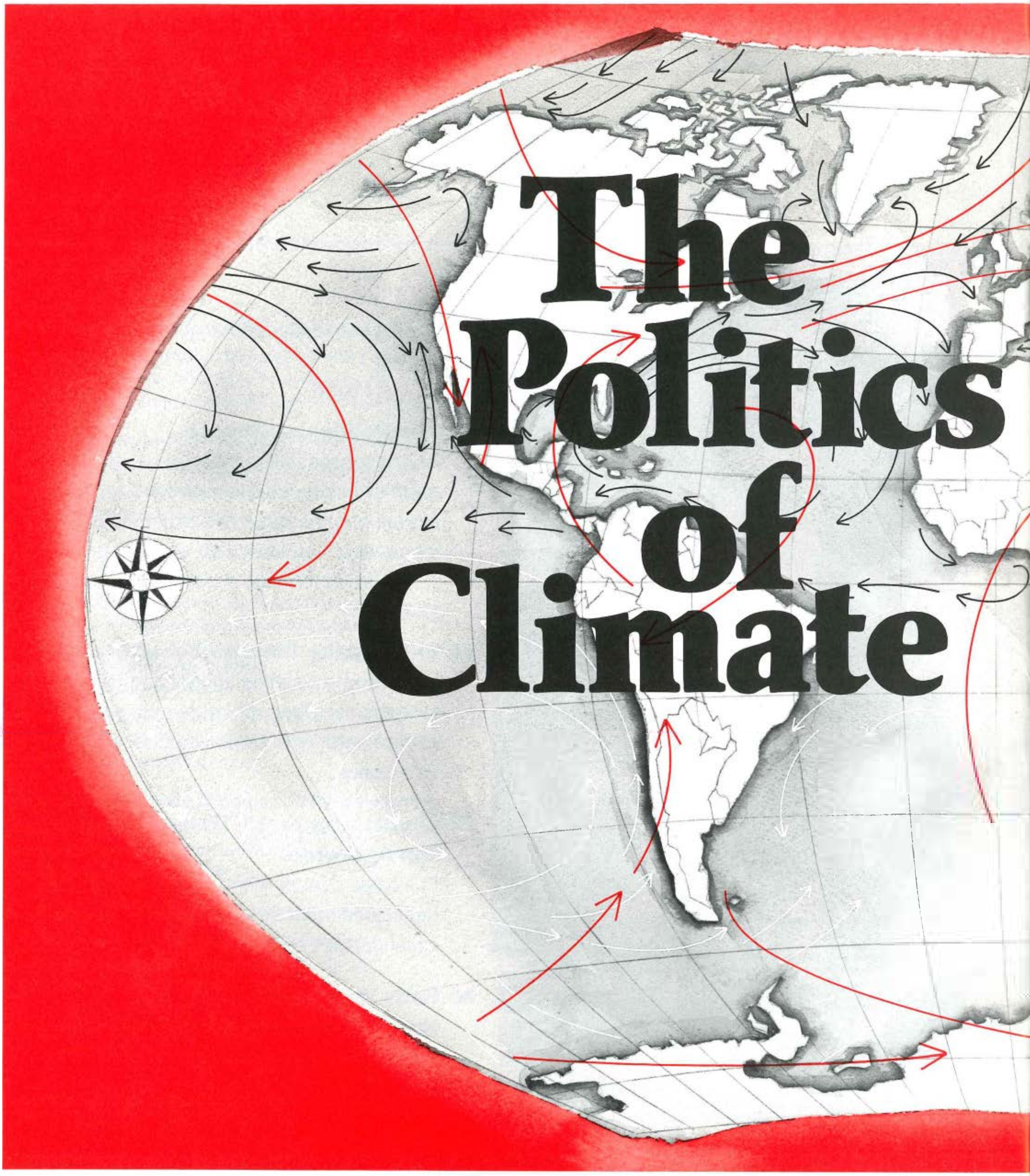


# The Politics of Climate



**As consensus builds that man is changing the earth's climate, policymakers are turning their attention to the issue and exploring potential responses.**

The greenhouse effect, once a subject of purely scientific inquiry, is rapidly emerging as an important public policy issue. The U.S. Congress reportedly devoted more time in 1987 to hearings on climate issues than it did to acid rain. Last December the Global Climate Protection Act of 1987 became law, requiring the president, through the Environmental Protection Agency, to develop and propose to Congress a coordinated national policy in this area. The law also calls for the State Department to seek international cooperation in limiting climate change and to work within the United Nations to promote the early designation of an international year of global climate protection. President Reagan and General Secretary Gorbachev included in their December 1987 summit communique an initiative to "promote broad international and bilateral cooperation in the increasingly important area of global climate and environmental change." The World Meteorological Organization and the United Nations Environment Program recently decided to form a joint panel to study the potential impacts of and responses to climate change. And in a related area, 49 nations meeting in Montreal last September approved an international protocol to limit production of chlorofluorocarbons (CFCs) and halons, chemicals that in addition to trapping heat in the atmosphere, destroy stratospheric ozone.

As Steven Shimberg, minority counsel for the Senate Environment Committee, puts it, "The scientists have caught the attention of the policymakers. Many members of Congress see this as the ultimate environmental issue." And as the history of environmental regulation amply demonstrates, policymakers are quite capable of taking action on issues long before all the relevant scientific uncertainties are resolved.

A sampling of comments from a Senate hearing held last December confirms Shimberg's view that at least some members of Congress take the matter seriously. Senator Mitchell: "The impacts of global climate change are of such consequence that we cannot afford to wait for all the questions to be answered with certainty. We are behind in our efforts to begin policy analysis and development to respond to this threat." Senator Baucus: "The uncertainty and potential magnitude of the impacts force us to begin to take responsible action now." Senator Chafee: "We must act on the information we have now. Each day of delay places us further down the path that threatens our very existence. We may be committing ourselves to environmental changes that are irreversible. By the time we have more information, it may be too late."

Why are these politicians so concerned about a problem that as far as the man on the street is concerned, has yet to appear? The basic reason is that they have been convinced by scientists studying the problem that if we continue on our present course we may substantially alter the earth's climate, with major economic, social, political, and environmental consequences. Because of the lag time in the earth's climate machine, we may have already set changes in motion whose full effects have yet to be felt.

Although many uncertainties remain about the greenhouse effect, scientists are largely in agreement on the broad outlines. The concentration of heat-trapping greenhouse gases in the atmosphere is steadily increasing as a result of man's activities. The most important gases are carbon dioxide ($CO_2$), responsible for about half of the effect, and methane ($CH_4$), nitrous oxide ($N_2O$), chlorofluorocarbons (CFCs), and tropospheric (lower atmosphere) ozone ($O_3$), which are expected to have a combined effect equal to that of $CO_2$.

Computer models predict that a buildup of greenhouse gases in the atmosphere equivalent in heat-trapping capability to a doubling of the preindustrial level of $CO_2$ will commit the earth to a rise in average temperature of 1.5 to 4.5°C (2.7 to 8.1°F). Because of lags in the earth, air, and ocean cycles, global temperatures may take some time to reach a new, higher equilibrium level. But once the gases are emitted to the atmosphere, the effects may be inevitable, according to current models. And the effective doubling of atmospheric $CO_2$ is expected within 50 to 100 years.

Many scientists would agree that because of uncertainties about key feedback mechanisms, which could exacerbate or dampen the warming, the actual changes may fall above or below the range of predictions now being made. Nobody knows for sure. But even the low end of the prevailing estimates—a 1.5°C warming—would create the warmest conditions experienced in recorded history. A 4.5°C rise would create a temperature regime last experienced in the Mesozoic era—the age of dinosaurs. The mercury wouldn't necessarily stop there, either. Gas concentrations above a $CO_2$ doubling could yield even greater warming.

Some researchers believe that greenhouse gas emissions to date have already committed the earth to a warming of 0.5 to 1.5°C. Recent analyses of temperature records over the past century reveal an overall warming of about 0.5°C, with the three hottest years occurring in the 1980s and five of the nine warmest since 1978. As EPRI Environment Division Vice President George Hidy puts it, "These observations do not prove a cause-and-effect link; temperatures cycle naturally and are still in the range of normal variability. Moreover, the earth did cool from the 1940s to the 1970s, despite increasing greenhouse gas concentrations. So while I'm not yet convinced that a greenhouse warming has begun, the warming trend over the past decade is certainly consistent with the view that it has."

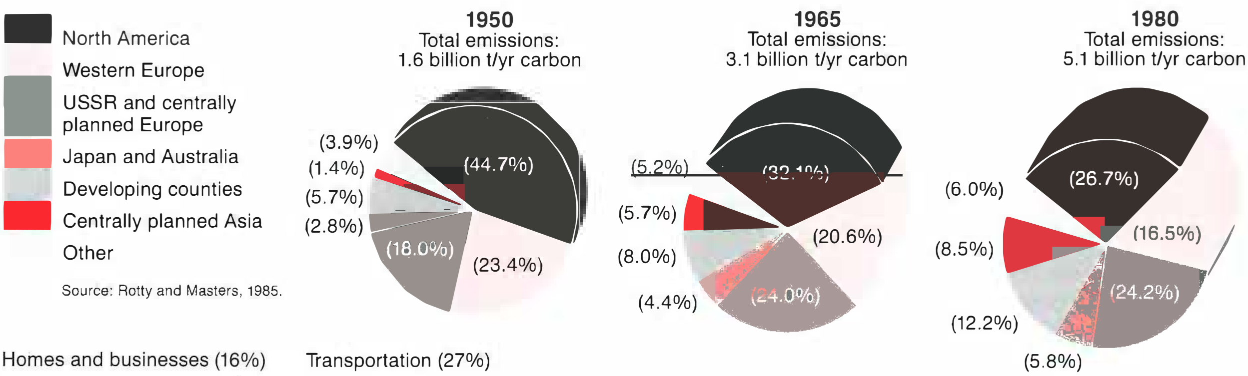
## What to do

There are three basic positions in the emerging greenhouse policy debate: more research is needed before we can respond effectively; climate change is inevitable, and we should prepare to adapt; we should start immediately to mitigate the changes.

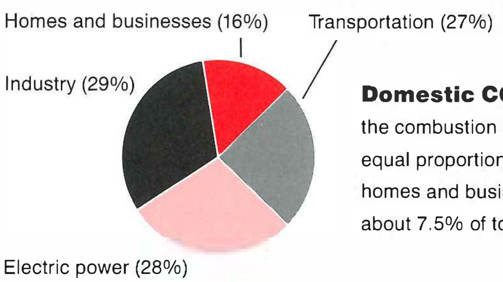
Frederick Koomanoff, who directs the Department of Energy's $CO_2$ research program, has long held that we need to better understand the problem before we adopt policies to mitigate or adapt to the changes. "There's going to be global warming," he says. "There's no question about that. That's physics. But what are the regions in jeopardy? What's going to happen where? That's the key, and that we don't know. When we run the models to see how well they reproduce past climate conditions on a regional basis—say the size of the American grain belt—they differ so completely that we can't really use

# Emissions and Effects

**$CO_2$ Around the World** Worldwide emissions of $CO_2$ more than tripled between 1950 and 1980, and the pattern of global contribution has been changing in parallel with the growth of industrialization. North America and Western Europe, together accounting for 68% of the $CO_2$ in 1950, represented only about 43% of the expanded total 30 years later. In contrast, the portion attributable to the People's Republic of China and developing countries in Africa, Latin America, and southern Asia grew from 7% to over 20% of the world total.

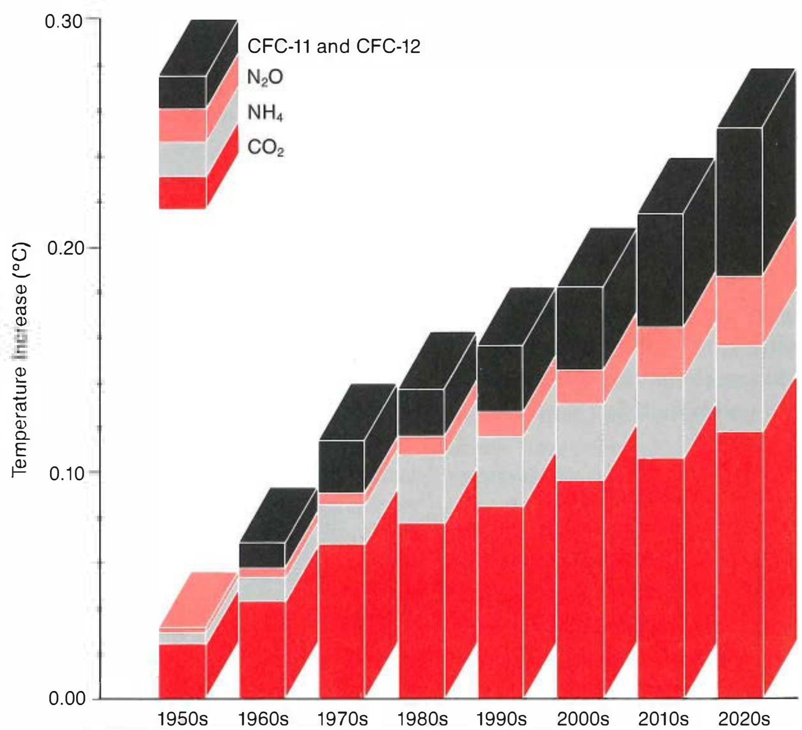



Source: Rotty and Masters, 1985.




**Domestic $CO_2$ Production** About a quarter of the world's $CO_2$ emissions are produced by the combustion of fossil fuels in the United States. This U.S. contribution comes in approximately equal proportions from industrial processes, electric power production, and transportation, with homes and businesses playing a somewhat smaller role. U.S. electricity generation accounts for about 7.5% of total worldwide $CO_2$ emissions.

**Decades of Change** Researchers believe that greenhouse gases will cause slow but significant warming of the atmosphere over the coming decades. Carbon dioxide ($CO_2$) has been the predominant concern in the past, but the effects of such gases as methane ($NH_4$), nitrous oxide ($N_2O$), and chlorofluorocarbons (CFCs) are expected to increase substantially in the future. The projections (right), based on a single model, show the predicted temperature rise for each decade resulting directly from the four groups of gases thought to be most important to global warming. The model predicts a cumulative increase of only about 1°C over the next half century; however, these results do not include environmental feedback effects, which can speed up or slow down the warming trend, or the accumulation of several other gases for which there are few data. Other models estimate a total temperature increase as high as 3°C for the same period.



them. There's always going to be uncertainty. But at least we have to know the direction of the changes in a given area, plus or minus, before we act."

Koomanoff agrees, however, that certain kinds of policy-related work do make sense right now. "We should start compiling data bases on the resources that are out there—agricultural systems, forests, fisheries, and their links to the economy, and we need to develop methodologies to manipulate these data so that we can identify which regions are in jeopardy."

The Environmental Protection Agency, at the request of Congress, is doing some of this already. Focusing on four case study areas—Southeast, Great Lakes, California, and Great Plains—EPA is carrying out a major assessment of the potential effects of climate change on forests, lakes, wetlands, agriculture, human health, and other aspects of the environment. The project also will identify policy options for adaptation to such changes and will flag key areas of scientific uncertainty. EPA expects final reports on these projects to be available by this autumn.

In many cases the uncertainty about regional climate changes will prevent researchers from drawing firm conclusions about the effects on a given resource. For instance, without knowing whether rainfall and soil moisture will increase or decrease in a given area during the growing season it is difficult to predict the impact on crop yields. What many of these studies will do then is to consider a number of climate change scenarios to define potential ranges of effects.

These kinds of "what if" studies are useful for understanding what might be at stake if climate does change and how adaptive responses might work. Coastal development planning, for instance, should consider the possibility that a greenhouse-induced warming may raise the sea level a few inches to a few feet in the coming decades. According to Stephen Leatherman, director of the Laboratory for Coastal Research at the University of Maryland, the earth's oceans have risen about six inches during the past century. As a consequence, 90% of U.S. beaches are eroding at a national average rate of slightly more than one foot per year, and many areas along the Atlantic and Gulf coasts are eroding three to five feet a year. Not only should roads and buildings be sited well back from eroding shorelines, claims Leatherman, but communities should recognize that even moderate rises in average sea level can allow destructive waves to reach much higher ground during severe storms.

Rising seas and other results of a global warming could have implications for utilities as well in areas ranging from plant siting to load profiles and the availability of hydro resources. EPRI recently cofunded a study on possible impacts of climate change on utility operations. Although such changes, if unanticipated, could be very costly to individual utilities, the study found that the costs could be significantly reduced with appropriate planning.

Not everyone agrees that we have enough information to start adapting to climate change. Barry Malac, technical director of the Woodlands Division of the Union Camp Corp., is dubious about the dire predictions some researchers are making about the impact of climate change on the forest products industry. "These changes are likely to be extremely gradual, often imperceptible, proceeding over decades or perhaps even centuries." Even for an industry that routinely plans 20 to 30 years ahead, as Malac explains, climatic fluctuations measured in decades or centuries "are for all practical purposes irrelevant to any reasonable resource and management planning."

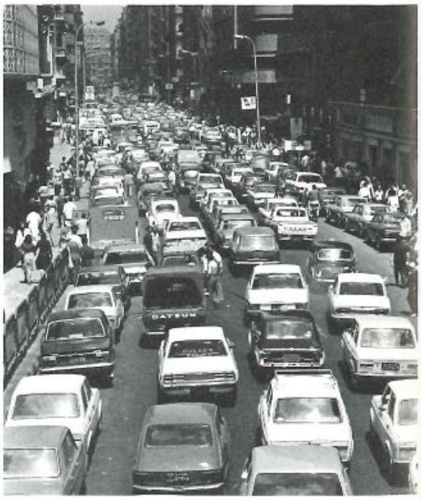
Comments like these reveal a wide range of opinion on the implications of climate change and the urgency of the need to adapt. Where the debate really

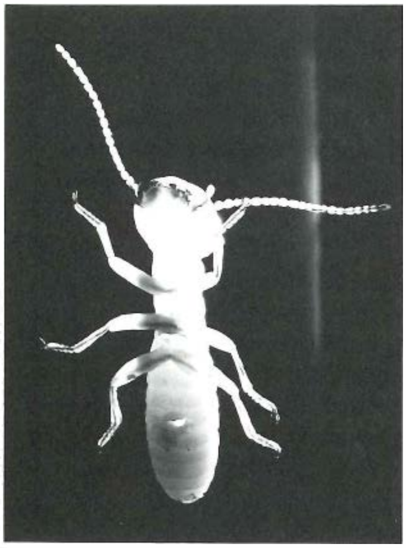
## A Multitude of Sources

Greenhouse gases are produced by a broad range of natural and man-made processes. The burning of fossil fuels for transportation, electricity generation, and manufacturing adds carbon dioxide to the atmosphere, as does deforestation. Methane is produced in significant amounts by rice paddies and wetlands and by the digestive tracts of farm animals and termites. Natural land emissions, fossil fuel combustion, and the use of fertilizer all add nitrous oxide to the air. Chlorofluorocarbons, historically used as propellants for aerosol cans and in the manufacture of insulating and packaging foams, are now being phased out of many U.S. commercial applications.

Λ Fertilizers

Auto emissions V





∧ Termites

∧ Rice paddies

∧ Industrial pollution

∧ Deforestation

Cattle ∨

Aerosols ∨


heats up, however, is in the discussion of what, if anything, should be done to ameliorate such change.

## Winners and losers

Because the sources of greenhouse gases are so diverse, any effective amelioration of global warming will require action by many nations. The task of reaching international agreement on mitigation strategies could be hampered, however, by the perception on the part of some countries that they might be better off in a warmer world. Climate models predict, for instance, that rainfall over the midcontinents might shift northward, improving growing conditions in Siberia and Canada but recreating the Dust Bowl in the American plains. Global rainfall would probably increase, harming nations in the path of more severe tropical storms but possibly helping arid regions like sub-Saharan Africa. Some changes, like more vigorous growth of plants exposed to higher $CO_2$ levels, might help many places, while other effects, like sea level rise, would be almost universally harmful.

Most nations—especially large, geographically diverse ones like the U.S., U.S.S.R., and China—would probably receive some mix of benefits and costs. For instance, a welcome warming in Siberia might be accompanied by less desirable changes in the western Soviet Union.

Although some nations may think they stand to gain, none can know for sure. They know some change is likely, but they don't know how fast it will arrive, how severe it will be, or how it will manifest itself locally. Moreover, many of the most profound effects may yet be unanticipated. Climate change may proceed gradually and almost imperceptibly or it "may come in sharp steps," as Columbia University geochemist Wallace Broecker told a Senate committee last year. "If so, then we must begin to think in terms of climate surprises that may, without warning, cause shifts in temperature and rainfall patterns."

Any government that gambled on being a net winner in the climate change sweepstakes thus would be playing with very limited information and for very high stakes. For climate is interwoven with the fabric of human society; we have built our world around it. To change it markedly is to tinker with something vast.

As Mason Willrich, now executive vice president of Pacific Gas and Electric Co., wrote in his 1975 book *Energy and World Politics,* "A substantial change in the earth's climate would inevitably force a worldwide political, economic, and social upheaval. We can adapt comfortably to large seasonal temperature variations, and we can endure occasional painfully hot, cold, wet, and dry spells. All human institutions rest, however, on the underlying balance of the world's climate."

Sir Crispen Tickell, ambassador to the United Nations from the United Kingdom, echoes Willrich's view. "With climate change the cards of economic advantage that we all take for granted would be redealt between countries, with very interesting results. But the biggest problem of all is change. In earlier times people could and did react to change with their feet—they just moved on to where conditions were better. But with increasing population, extreme population density, and resources that are exploited to the maximum, large movements of people would scarcely be possible. In our overstretched human world all change means dislocation."

Without a doubt, it will be difficult to achieve international cooperation to mitigate climate change. But it may be easier to achieve in today's state of shared uncertainty about local and regional effects than it would be if nations knew (or thought they knew) who the winners and losers would be.

So far, the cooperative spirit appears to be prevailing as national, bilateral, and international dialogue on the greenhouse issue accelerates. Later this year EPA is expected to complete a study of climate-related policy options, their likely ramifications, and their effects. EPA Administrator Lee Thomas led a U.S. delegation to Moscow last February that reached an agreement with their Soviet counterparts to set up a bilateral working group to explore greenhouse policy issues. In 1987 a similar bilateral arrangement was reached between EPA and the People's Republic of China. The Organization for Economic Cooperation and Development recently stepped up its efforts to study the environmental, energy, and socioeconomic implications of climate change and the impact of potential control measures for greenhouse gases. And the World Meteorological Organization and United Nations Environment Programs are in the process of establishing an intergovernmental panel on climate change to study all aspects of the issue, from the scientific uncertainties to social and economic impacts and potential responses.

What is most notable about these activities is that the issue is no longer solely in the scientific realm. Major scientific uncertainties clearly remain, but the nations of the world—including many developing countries, as witnessed by the strong interest within the United Nations—are starting to ask, what should we do about this?

## How to slow the change

Many of the major policy options have already been articulated, and they center on slowing the buildup of heat-trapping gases in the atmosphere. Specifically, the key options appear to be reducing emissions of CFCs, reducing and reversing tropical deforestation, and limiting combustion of fossil fuels.

Proponents point to the Montreal accords of last September, in which negotiators from 49 nations agreed on restrictions for CFCs as an important example of how nations can reach agreements on global environmental issues. The principal impetus was concern that CFCs are depleting the stratospheric ozone layer that shields us from harmful solar ultraviolet radiation. But CFCs also act as greenhouse gases in the lower atmosphere. So if the Montreal agreement is ratified by at least 11 nations representing two-thirds of global CFC production, it will also help ameliorate a greenhouse warming. Among the key provisions are a freeze in CFC production at 1986 levels to take effect in 1989 and a 50% cut in CFC use by 1999.

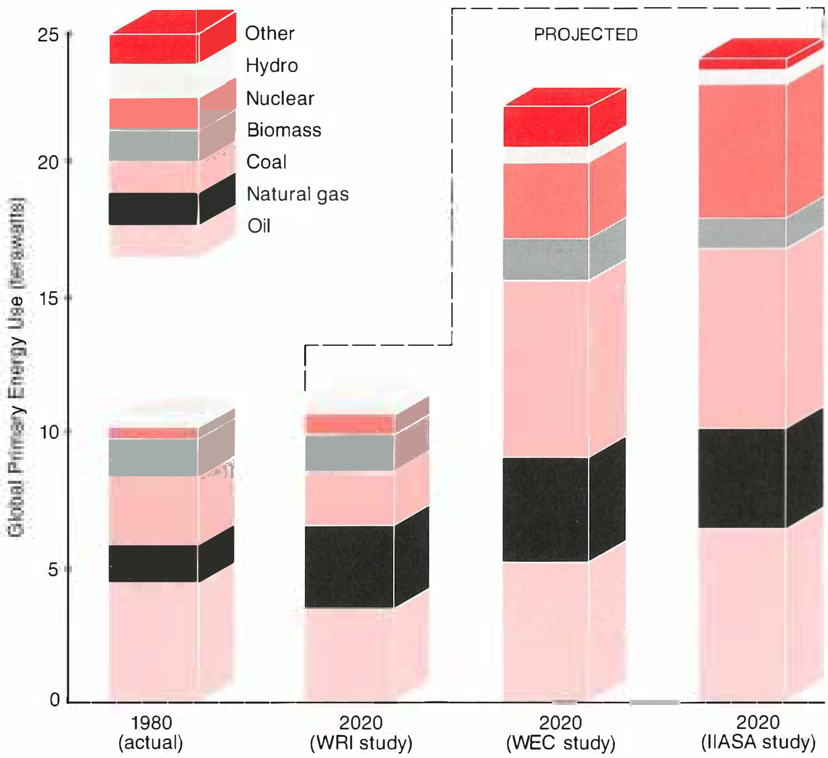
Two factors made agreement on CFCs easier than might be the case with other greenhouse gases. The negotiators perceived a clear and present danger with regard to ozone depletion (higher risk of skin cancer and cataracts), and CFCs are used for specific commercial purposes (like refrigeration and production of insulating foams) for which substitute compounds exist or are under development. In other words, the costs to society of reducing CFC use are not very high.

New findings that ozone levels are falling worldwide—not just over Antarctica, as had been previously thought—have some scientists and policy analysts calling for even stricter controls or an outright ban on CFCs. "The composition of the atmosphere may be changing far more rapidly than we had expected," comments Irving Mintzer, a senior associate at the World Resources Institute (WRI). "Clearly the Montreal protocol is not enough to reduce the risk."

Others argue, however, that the link between CFCs and the 5% worldwide ozone decline from 1979 to 1986 is not clear because ozone levels are thought

# Energy Use and Climate Change

Because fossil fuel combustion contributes more than half of all greenhouse gas emissions, the rate of climate change may depend largely on future energy policies. The results summarized below convey the range of thinking on how energy use will change in the next several decades. Differing views on the potential for energy conservation are responsible for much of the difference in the scenarios. The World Resources Institute (WRI) study suggests that ambitious investments in conservation can keep energy use roughly constant over the next 30 years. The studies by the World Energy Conference (WEC) and the International Institute for Applied Systems Analysis (IIASA) predict that even with substantial conservation, world energy use will roughly double by 2020, with much of the increased supply coming from coal and nuclear power.




to rise and fall in natural cycles, perhaps associated with changes in solar activity. Ozone levels reportedly rose 4% in the 1960s.

Deforestation is another important source of greenhouse gas buildup. When forests are leveled and the trees burned or left to rot, the carbon in the biomass is released as $CO_2$. Conversely, growing plants absorb $CO_2$ from the air and, through photosynthesis, fix the carbon in their tissues. There is a longstanding scientific debate about whether the world's biomass is now a net absorber of $CO_2$ or whether deforestation and organic decay is proceeding at such a rapid pace that plants are now releasing more $CO_2$ than they are absorbing. One recent review article postulates that tropical deforestation adds between 0.4 and 1.6 billion tons of carbon to the atmosphere each year, which is about 10–30% as large as the 5 billion tons emitted by fossil fuel combustion. Whatever the actual figure, a reduction in deforestation and an increase in reforestation would undoubtedly help to slow the rate of increase of atmospheric $CO_2$.

Much of the world's deforestation is occurring in developing nations. Trees are being cut to provide fuelwood and charcoal, to clear land for cattle ranching, roads, and settlements, and for lumber. Reversing this trend is difficult, as rural development specialists have learned in recent years. But progress is being made in a number of ways.

Aid organizations have developed more-efficient stoves for villagers who use wood for cooking and heat. Low-cost, efficient, liquid-fueled stoves are being developed to help reduce fuelwood demand. Reforestation programs have been launched. International lending institutions like the World Bank have started to link forest preservation requirements to the loans they provide for roads and infrastructure development. Despite these efforts, forests in the tropics alone are being cleared at a rate of about 40,000 square miles a year (an area the size of Virginia), and experts maintain that far more resources will have to be devoted to this problem if it is to be brought under control.

$CO_2$ is not the only greenhouse gas with biologic origins. Some of the nitrous oxide being emitted to the atmosphere comes from agricultural fertilizer, and much of the methane release comes from anaerobic decomposition of organic matter in flooded rice paddies, termite mounds, landfills, and the digestive tracts of livestock. Researchers are just beginning to explore whether changes in fertilizer formulations and agricultural practices would have much impact on these emissions. Rice doesn't have to be grown in flooded ground, for instance; the flooding is principally for weed control. Some agronomists even argue that higher yields can be achieved without flooding. If this proves true, methane emissions could fall as a side effect of changes in cultivation practices aimed at increasing yields.

## EPRI Resolving $N_2O$ Uncertainty

EPRI's research budget in the area of climate change is modest, so the Institute tries to target its funding to resolve small pieces of the greenhouse puzzle that are not being addressed by other research organizations. One example is the Institute's work on nitrous oxide ($N_2O$).

$N_2O$ is a greenhouse gas with a very long (150-year) lifetime in the atmosphere. Atmospheric concentrations of this gas are currently rising by about 0.25% per year. Roughly half of the emissions are thought to come from natural sources. The rest comes from combustion of fossil fuels and biomass and from agricultural fertilizer. Little is known, however, about the chemistry of $N_2O$ formation during fossil fuel combustion or the amounts being released from power plants. EPRI has three projects under way to resolve this uncertainty.

Measurements of $N_2O$ are now being taken as a routine part of the Institute's $NO_x$ monitoring effort. George Offen, manager of the Air Quality Control Program, explains: "Current $N_2O$ emissions data are sparse and sometimes contradictory. We want to get a better handle on the emissions, as well as a better understanding of the impact of $NO_x$ controls on those emissions." To improve on the expensive, error-prone lab analysis approach, EPRI contracted with the University of California at Irvine to develop an instrument for on-line $N_2O$ monitoring. Offen believes that this method will provide more-reliable data and allow $N_2O$ emissions to be measured under a wider range of conditions. The Irvine team will also use the instrument for bench-scale tests of the impact different $NO_x$ control techniques have on $N_2O$ emissions. □

There is some hope, then, that biotic sources of greenhouse gases could be controlled somewhat, although the efficacy of such measures remains highly uncertain. The largest single source (more than half) of greenhouse emissions, however, is the extraction and use of fossil fuels in vehicles, buildings, factories, and power plants. Thus, the core of the debate about how to ameliorate a greenhouse warming ultimately comes down to issues of energy policy.

### Energy policy and greenhouse warming

Because fossil fuel emissions contribute not only to the greenhouse problem but to acid deposition, urban smog, and stratospheric ozone depletion ($N_2O$ is implicated in the breakdown of ozone), proponents argue that greenhouse control measures that reduce the use of fossil fuels can yield multiple benefits. Greater emphasis on efficiency in energy supply and use is often mentioned. Specific measures that have been proposed include a carbon tax to discourage use of such high-$CO_2$-releasing fuels as coal and coal-based synfuels; stricter vehicle mileage standards; a requirement that the climate implications of projects be considered in environmental impact statements; and fuel-switching to natural gas, nuclear power, and renewable energy sources like wind, solar, and annually cycled biomass.

The question of what can be achieved with energy conservation is the "jugular" of the issue, as WRI President Gus Speth puts it. His organization recently sponsored an international study, which concluded that an ambitious, cost-effective program of efficiency improvements in the energy sector could keep world energy consumption essentially flat over the coming 30 years, while allowing for economic growth and population increase.

For every low-energy scenario, however, there are others that are less optimistic about conservation's potential. EPRI President Emeritus Chauncey Starr points out that "on a per capita basis, citizens of developing nations use one-ninth as much electricity as residents of the industrialized world. As poorer nations strive for higher standards of living in the coming decades, they will inevitably consume more energy." Citing a World Energy Conference study, Starr maintains that even with ambitious energy conservation efforts, global energy use will at least double and perhaps triple by the year 2060.

Even if world energy demand were to stay roughly constant, the question arises as to what fuels will be used to supply that demand. Some analysts argue that policies should encourage a switch away from coal toward natural gas because natural gas releases only half as much $CO_2$ per energy unit. And if the gas is burned in high-efficiency combustion turbines, electricity can be generated with only one-third the $CO_2$ output of conventional coal combustion.

Even if there were enough natural gas available to displace much of the world's coal use, a point that Starr questions, he argues that such a policy would be ill-advised. "Coal will continue to be widely used, especially in the developing world because it is abundant and inexpensive. It is a pipe dream to think that poor nations will forgo the use of cheap energy resources to avoid some as yet unproven change in climate. Moreover, natural gas is too valuable as a petrochemical feedstock. I think it is almost a scandalous waste of natural resources to burn it to make electricity."

EPRI President Dick Balzhiser differs on this point. "With the coal gasification technology that is now available, we have the capacity to derive the same chemical building blocks from coal. I think one can argue that if natural gas is available today and it competes well with oil, coal, or any of the other op-

## Greenhouse Policies Emerge

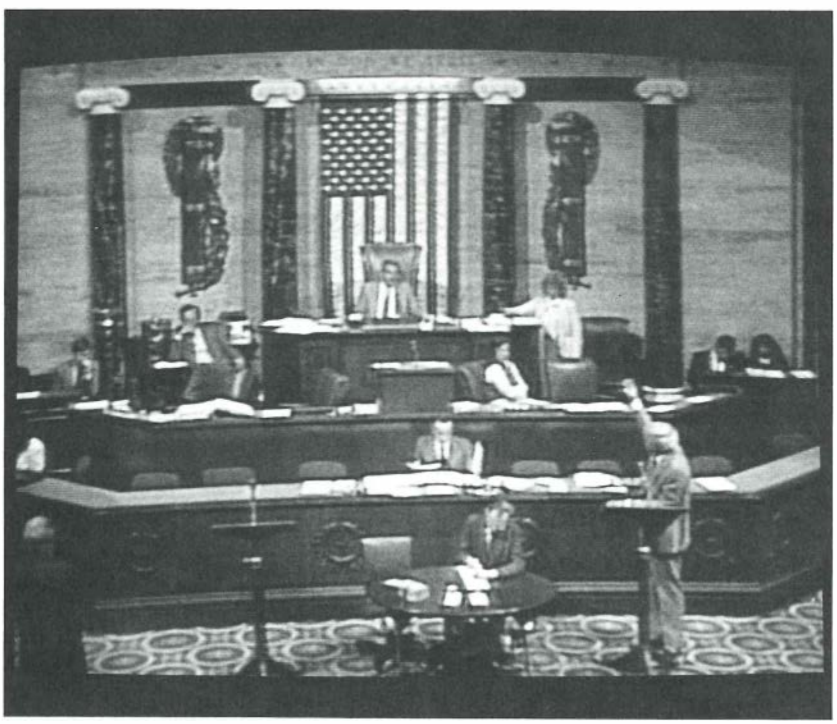
Although scientific understanding of man's impact on climate is incomplete and there is not much precedent for multilateral agreements on environmental issues, domestic laws and international pacts related to climate change are beginning to emerge and the pace of discussion is building.

- **Global Climate Protection Act of 1987** Passed by the U.S. Congress last December, this law requires EPA to develop a coordinated national policy on climate change and charges the State Department to seek international cooperation in limiting such change.

- **Montreal Protocol on the Ozone Layer** An international agreement approved by representatives of 49 nations last September to limit the production of chemicals that destroy stratospheric ozone: CFCs (also a potent greenhouse gas) and halons. To take force, the protocol must be ratified by at least 11 nations representing two-thirds of world consumption of CFCs. If ratified, the protocol would freeze CFC production in 1989 at 1986 levels and require a 50% cut by 1999. As of mid May 1988, the United States and Mexico had ratified the protocol.

- **Bilateral Agreements with the USSR and China** In the past few years, EPA has established bilateral agreements with the Soviet and Chinese governments to explore greenhouse policy issues.

- **UNEP–WMO Policy Initiatives** The United Nations Environmental Program and World Meteorological Organization, in conjunction with a number of nongovernmental institutions, have sponsored several international conferences in the past few years to discuss the development of policies for responding to climate change. UNEP is considering establishment of an intergovernmental committee this year to explore greenhouse policy options under U.N. auspices.



tions for energy supply, it should be used."

The gasification option also raises another possibility—that $CO_2$ could be stripped from coal-derived syngas and stored or fixed chemically to prevent it from entering the atmosphere. Several studies have looked at the possibilities of disposing of $CO_2$ by pumping it deep into the ocean, injecting it into depleted natural gas reservoirs, or expanding its use in tertiary oil recovery. Although these options are all technologically feasible, some analysts doubt they would be cost-effective in many locations.

Gordon MacDonald, vice president of The MITRE Corp., comments: "There are some very simple thermodynamic facts of life. Once you've combined carbon with oxygen (to make $CO_2$), to stuff it back into the earth or otherwise dispose of it you essentially have to use nearly the same amount of energy as you gained in the burning process to begin with. So it doesn't look as if it would be economic to remove $CO_2$ even in principle."

EPRI Vice President Dwain Spencer takes a different view. He admits that we do not yet know how to technically and economically fix and store large amounts of $CO_2$, but he believes that with adequate R&D, viable options could be developed. Such measures would inevitably raise electricity costs, though it is not yet clear by how much. Typical estimates for the currently conceived approaches show cost premiums of roughly 30 to 100%.

Natural and synthetic gas aren't the only supply options being proposed, however. Renewable energy supplies also hold promise for electricity production in some settings and more widely for low-temperature applications like water and space heating. The contribution of renewables to global energy supplies has grown steadily over the past 15 years and is expected to increase in importance in the future.

One of the most interesting energy

## What's at Stake for Utilities?

If the earth's climate does change markedly in the next century, societies and institutions will have to adapt. Foresight and planning can help make this adaptation easier. The electric utility industry took a step in this direction recently by conducting a preliminary "what if" study to explore how utility operations might be affected if greenhouse-induced climate changes do occur.

Cosponsored by EPRI, the Environmental Protection Agency, Edison Electric Institute, and the New York State Energy Research and Development Administration, the study concluded that climate change may entail significant capacity and cost implications for utilities. Conducted by ICF Inc., the study looked at only two of the possible ways that utilities might be impacted: the effects of projected temperature rises on heating and air conditioning loads, and the implications of reduced stream flow on hydroelectric resources. The work examined two case studies: a southeastern utility and the member companies of the New York Power Pool.

Focusing on the year 2015, a point well within utility planning horizons, the analysis suggests that temperature increases of slightly under 1°C would increase the need for new generating capacity in both service territories by 10 to 20%, leading to hundreds of millions of dollars in increased electricity production costs.

The study also looked at the implications of alternative planning assumptions made by the utilities with regard to climate change. If the southeastern utility planned for and phased in new combined-cycle generating capacity in anticipation of a warming that never occurred, it would find itself with excess capacity, costing an estimated $11 million in the study year of 2015. If, however, the utility did not plan for the warming and it did occur, the costs of hurriedly adding relatively expensive short-term supplies like oil- and gas-fired turbines and purchased power were shown in this analysis to be even more expensive—about $55 million for the year 2015. In this scenario, then, the risk of not anticipating the warming is five times as great as the risk of planning for it and having it not occur.

Whether or not the numbers in this scenario are accurate, it is a useful exercise to evaluate in even a qualitative way what might be at stake for the industry, maintains Richard Richels, manager of EPRI's Risk Management Program: "Bear in mind that we looked at only two utilities in a single year and have considered only two of the ways that climate change could affect utility operations. Once we integrate across many years, many impacts, and many utilities, we may find that the cost to the industry and its customers of guessing wrong about climate change may be very high indeed."

Acknowledging that this study was only a "preliminary cut at the problem," Richels suggests that future impact assessments should consider more of the pathways by which climate change can affect utilities, such as demographic shifts, changes in pumped irrigation loads, changing storm patterns, and the implications of a rising sea level for coastal plants. He also maintains that the methodology can be improved and that the impacts need to be assessed regionally across the country to give a more balanced and comprehensive view. □

supply issues in the greenhouse debate centers on nuclear power. Nuclear supporters have long argued that if the greenhouse effect is indeed a serious problem, nuclear power can help solve it by displacing fossil fuel consumption. (Nuclear fission releases no greenhouse gases.) Some nuclear critics are starting to reexamine their positions along these lines.

Senator Tim Wirth, a prominent environmentalist not generally considered a nuclear proponent, made the following comments at a recent Senate hearing on the greenhouse issue: "This is counterpolitical—there's a kind of nuclear measles in this country where people want to quarantine anything that relates to nuclear—but if [we're] serious in this area it seems we ought to be doing more with nuclear and less with coal."

Even the World Resources Institute, firmly grounded in the environmental community, argues halfheartedly that we should preserve the nuclear option. Limited research on simpler, safer reactor designs should continue, comments Speth, "although in the 15 to 20 years that it is likely to require to design, test, and build this new technology, many safer and more economic alternatives are very likely to become available."

### Who should lead?

Whatever energy policies are chosen, the United States cannot solve the greenhouse problem alone. It is a global issue. The United States produces about one-quarter of global CFC emissions and a similar proportion of man-made $CO_2$ emissions. Of the U.S. contribution to $CO_2$ loading, about one-quarter comes from electric utilities; the remaining three-quarters comes from automobiles, factories, and other combustion sources.

U.S. and Western European fossil fuel $CO_2$ emissions have been fairly stable since the early 1970s, but emissions from the eastern bloc, China, the Pacific Rim, and developing nations are rising.

Emissions from developing nations, in particular, are expected to grow substantially with population growth and industrialization. China, for instance, is drawing heavily on its coal reserves to fuel its development efforts.

Although the United States cannot unilaterally reverse the trend in greenhouse gas emissions, Rafe Pomerance of WRI argues that it can provide much needed leadership in this area. "The Montreal accords [on CFCs] would never have been reached without consistent American pressure on the world community over a 10-year period. We should be proud of our role in developing that agreement, and we should show the same kind of foresight and perseverance in convincing the world to control greenhouse gas emissions.

"The U.S., the U.S.S.R., and China control more than 80% of the world's coal. Here is an issue in which the fate of the planet in some sense rests in the hands of large continental powers and the leadership that they exhibit on this question."

Pomerance maintains that the government will not act alone, however. "If the industrial leadership isn't there, this problem won't be solved. It has to come from industry, which has to agree that this is a serious threat, has to be part of the solution, be out there leading the charge."

Not everyone believes the situation is so urgent, however. "That's such a typical argument for any environmental issue," says Bill Harrison, formerly senior vice president of Southern Company Services, and chair of the electric utility industry's Clean Air Act issues group. "The advocates always think nobody is taking them seriously enough, and everybody ought to rally behind their cause. My skepticism—and I suspect that many in the industry share my view—is based on the way that a lot of environmental issues have been treated in the last two decades. A little bit of information is extrapolated into the worst-case scenario in order to whip up a lot of interest.

"I think the responsible position for industry leaders is to stay informed and wait until the facts are in. If the consensus within EPRI and other groups working on the science is that we really do have an urgent and serious problem and that the industry has to face up to it, I think the industry would. The leadership is there. It's a question of persuasion."

EPRI's Balzhiser comments, "We have always been urged by our Board and executives in the industry to give them the scientific fact base they need to make judgments, and that means an early warning alert on any issue, whatever its implications. We've been limited in what we can do on this issue by resource constraints, but the events of the past year and the growing politicization of the issue may require that we increase our attention to our timetable for work in this area."

Mason Willrich of Pacific Gas and Electric Co. echoes Balzhiser's sentiments: "The institutional and policy issues that are emerging in this area are absolutely imperative for the country to address. And the industry needs to take a leadership role in that process."

The challenge of establishing the facts and informing decision makers extends well beyond the bounds of the utility industry. Ambassador Tickell explains that government leaders throughout the world will not readily make hard political choices to address the greenhouse issue. "They will ask three basic questions: Can you prove it? What will happen and when? What should be done about it?"

In addition to calling for stepped-up research on the scientific uncertainties, the potential effects, and the available policy options, Tickell has a further suggestion. "If government leaders are to be persuaded to take action—and remember that most of them are not scientists—then some catalyst in the form of a commission or panel of people, distinguished in political as well as scientific life, might be created. I see the function of such a body as threefold: to draw up an inventory of the causes of warming and the corresponding remedies; to draw up a code of good international behavior to act as a reference framework around which consensus could be built; and last, to examine the possibility of a network of agreements that might sooner or later have more-binding characteristics.

"Each stage represents an ascending order of difficulty. It would also represent a progression in time so that each could reflect the needs of the problem as it and public awareness of it develop.

"We live on a vulnerable planet. The multiplication of our own kind and the way we've changed the land, sea, and air around us require us to follow through the logic of what we've done and to manage the consequences. We should start before it is too late." ■

**Further reading**

*Potential Effects of Climate Change on Electric Utilities.* Final report for RP2141-11 prepared by ICF Inc. Forthcoming.

Chauncey Starr. "Global Climate Change and the Electric Power Industry." Presentation to the National Climate Program Office Strategic Planning Seminar, January 5, 1988. (Available from Dr. Starr's office at EPRI.)

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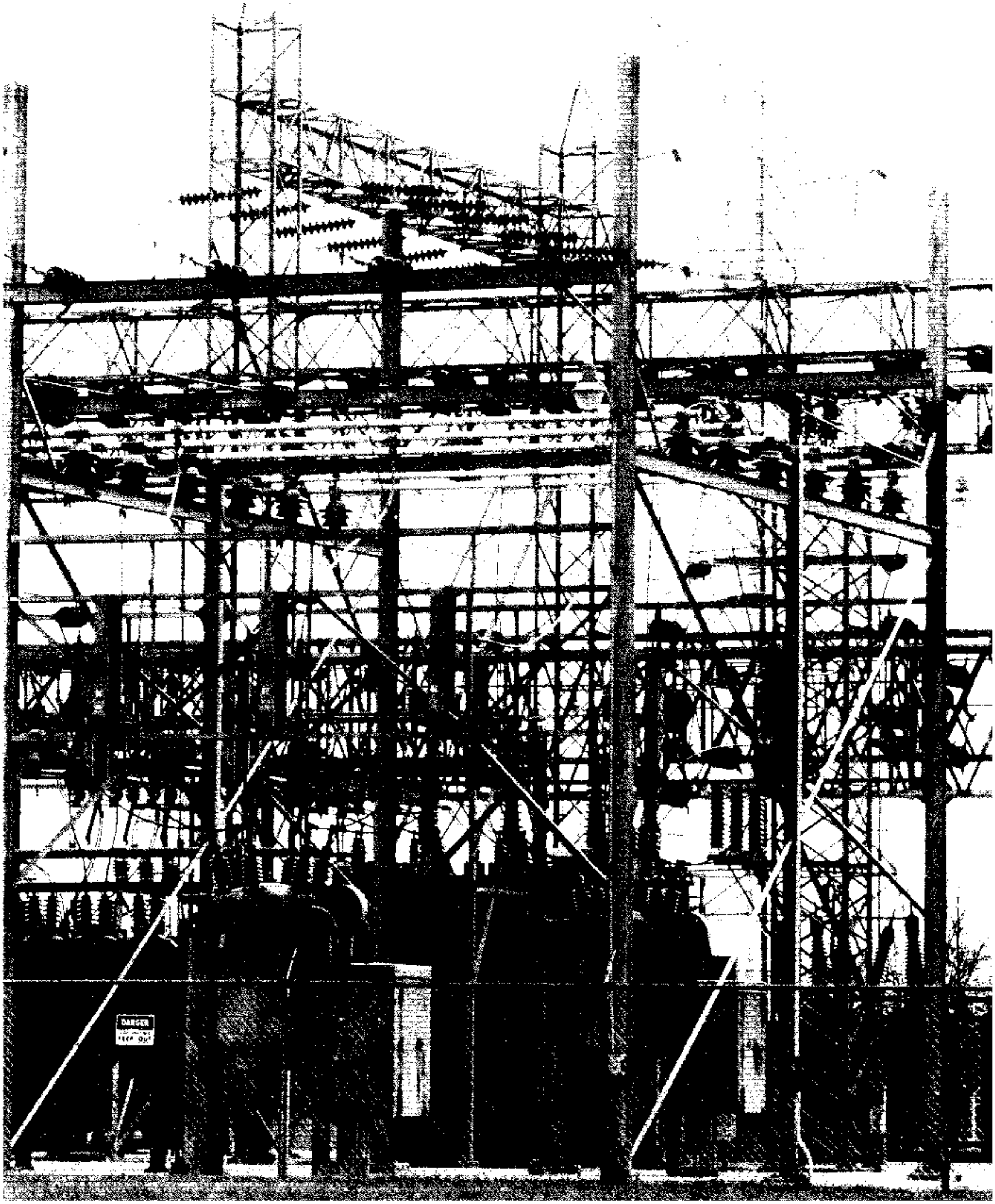
This article was written by Michael Shepard with background information from three EPRI Vice Presidents, George Hidy, Dwain Spencer, and Kurt Yeager. Additional information was provided by a number of EPRI staff members: Stephen Baruch, Leonard Levin, Michael Miller, George Offen, Ralph Perhac, Richard Richels, Ian Torrens, and Thomas Wilson.


DANGER

# Building the Smarter Substation

**Integrated substation control and protection systems are the perfect complement to modern solid-state relay equipment—the new digital technology can deal with more data faster and cheaper and offers advanced O&M capabilities as a bonus.**

When lightning causes a flashover on a transmission line or bus, or a fault develops in a high-voltage transformer, the affected equipment is isolated from the rest of a utility system by circuit breakers in a transmission substation. Many of these circuit breakers are still controlled by electromechanical protective relays, but over the last 20 years, solid-state electronic relays have become increasingly popular. Now, thanks to long-term EPRI research, the control and protection functions of a transmission substation can be integrated into a digital, microprocessor-based system that is less expensive, offers lower operations and maintenance costs, and provides a new level of operating flexibility.

What this means for a utility considering construction of a new substation or connection of a new transmission line to an existing substation is a probable 10–20% saving in the cost of relay and control equipment. In addition, several new functions that were previously too expensive for routine operations will be available automatically, including estimation of fault location, self-checking of equipment operations, capability for remote adjustment of relay settings, and detailed on-line collection of data from disturbances.

Over the long term the availability of such equipment may result in further savings by allowing utilities to operate transmission lines and transformers closer to their performance limits and thus avoid capital costs associated with adding new equipment. Advanced on-line equipment diagnostic capability is also within reach. "Until recently, digital systems for automation of substation operations would have been too expensive," says Narain Hingorani, vice president of the Electrical Systems Division. "As digital electronics became more powerful and less expensive, however, it became feasible to place microprocessors at various pieces of equipment and to link them together in an integrated system. We recognized the potential of this technology about nine years ago and began to push development of automation systems that are now being introduced as commercial products."

## Less wiring, more data

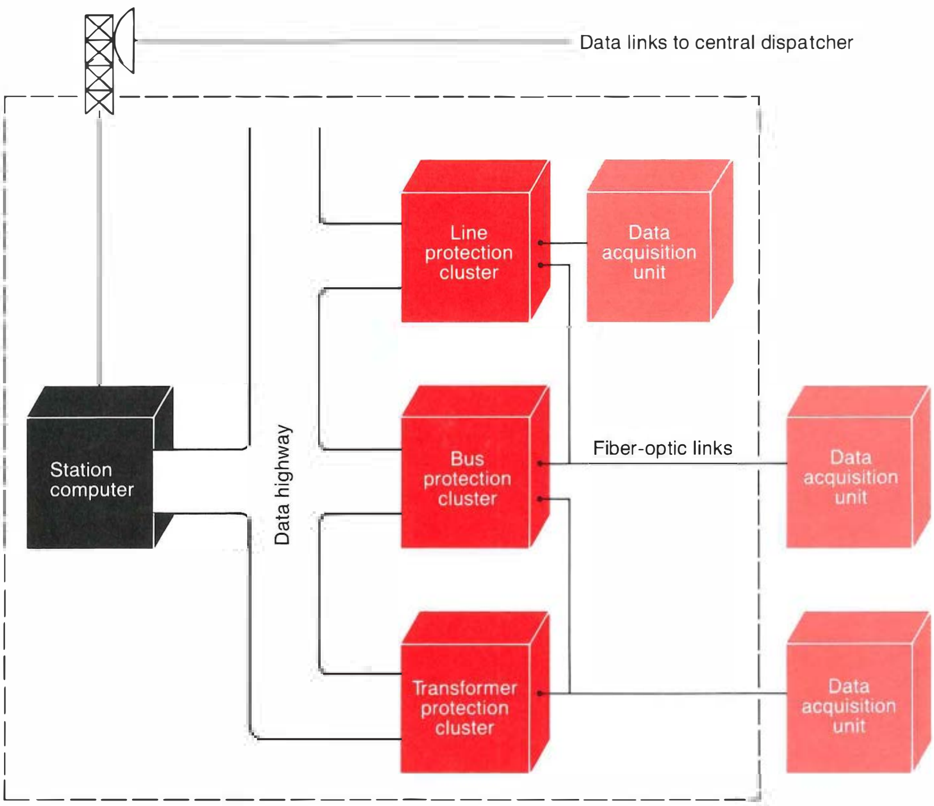
The economic and technical advantages of microprocessors result from their ability to handle large amounts of information with fewer components. In a substation, for example, a few microprocessors can handle input from several sources more or less simultaneously. Data can be passed from one processor to another, thus eliminating the need for much redundant equipment and wiring. The trick is to sample currents and voltages digitally from various sensors at a high frequency (16 times per cycle has been chosen for the system) instead of having individual analog signals distributed over separate wires. The main technical challenge addressed by EPRI research on transmission substation automation was how to organize numerous control and protection components into an integrated system. A type of organization, or system architecture, was needed that would balance cost reduction and enhanced performance, while providing sufficient redundancy to enable the system to perform even if any single component failed. The microprocessors used in this project are similar to those in personal computers.

The system architecture chosen involves three levels of microprocessors and associated electronics that are linked hierarchically. At the lowest level are data acquisition units, which serve as an interface between the power system and the control system. Analog input data from individual power equipment are converted into the digital form and passed up the hierarchy for processing. Commands from microprocessors higher up in the control system are, in turn, converted in data acquisition units into a form that causes some action, such as tripping or closing a circuit breaker.

The data acquisition units represent the most expensive portion of the integrated protection and control system, accounting for approximately 40–60% of the total system cost. The high cost is because these units require a large number of discrete circuits, which must be electrically isolated from high voltages and physically protected from damaging electromagnetic fields or heat. Signals from the data acquisition units are re-

## Integration for Better Control

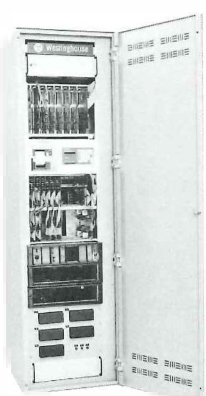
Microprocessors similar to those in personal computers are the key to new integrated control and protection systems for transmission substations. The microprocessors are linked together in a three-tiered architecture, beginning with data acquisition units (DAUs) that monitor equipment status at critical points throughout the substation. Digital signals from the DAUs are transmitted through fiber-optic cables to indoor protection clusters, which coordinate the information and decide when to open and close circuit breakers. Coaxial cable connects all the protection clusters, serving as a data highway for linkage to the top level of control—the station computer. The computer coordinates action among the clusters, stores data on power system events, and is a communication connection to a utility's offices or central dispatcher.





Station computer


Yard data acquisition unit


Protection cluster and data acquisition unit in one enclosure

ceived by a protection cluster, the second level of the architectural hierarchy. Each cluster coordinates the information gathered by the data acquisition units under its command and, in turn, controls the opening and closing of circuit breakers. Computations to locate faults in the power system are also executed at this or the next higher level of the hierarchy.

A single protection cluster and the data acquisition units attached to it constitute a stand-alone unit that can be added to existing substations without creating a fully integrated system. A new transmission line, for example, could be protected by using such stand-alone units at existing substations on either end. (The same hardware and software modules are used in both the integrated system and stand-alone units.)

The highest level of the microprocessor hierarchy for control of an entire substation is the station computer, which coordinates actions among multiple protection clusters and stores data captured from events on the power system. This computer has a large memory, which can be used, for example, to capture enough data from a fault to produce an oscillographic record of the current and voltage changes that occurred. Because substations are often unmanned, the computer also provides the capability of having a communication connection to a utility's offices or a central dispatcher.

The substation computer and all protection clusters share information through a data highway—physically, a coaxial cable with multiple connection points. During normal operation, the data highway enables the substation computer to poll each protection cluster once every 100 milliseconds for some data and about once a second for other data. In addition, the operation of the data highway will continue for critical functions even if the substation computer fails.

Usually, the substation computer and all protection clusters would be located inside a single control house. Commu-

# Dialog on the Data Highway

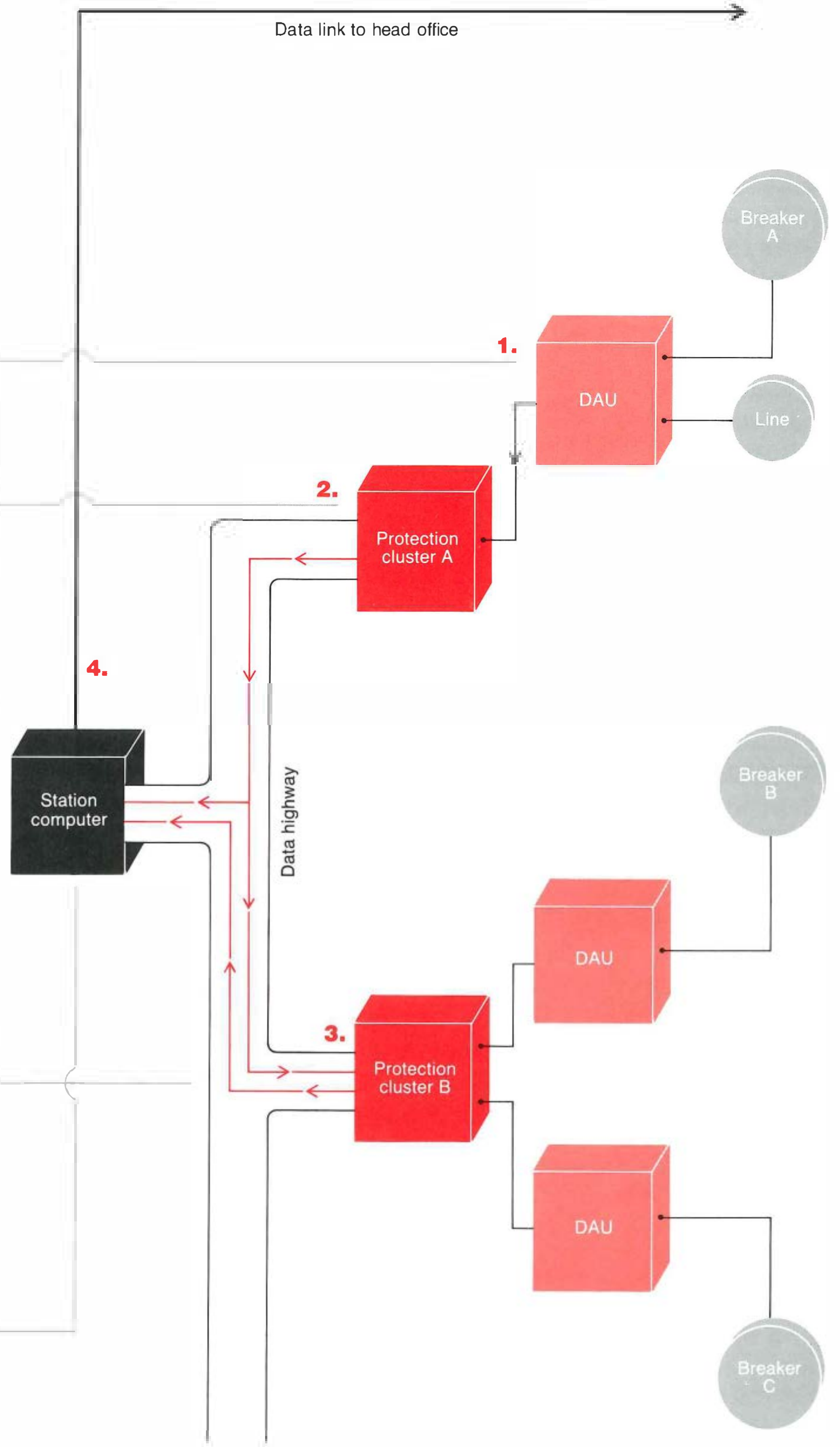
Interactive digital communication among the new system's microprocessors allows faster analysis and mitigation of problems than do conventional systems, and it also provides a continuous record of each incident as it develops. In the example below, the control and protection system must deal with the failure of Circuit Breaker A to shunt off a fault current.

**1.** *Cluster A, I still sense a large current on the line.*

**2.** *The fault current is lasting too long, so Breaker A must be inoperative. Cluster B, open appropriate breakers. Station Computer, I've experienced a breaker failure and have instructed Cluster B to act.*

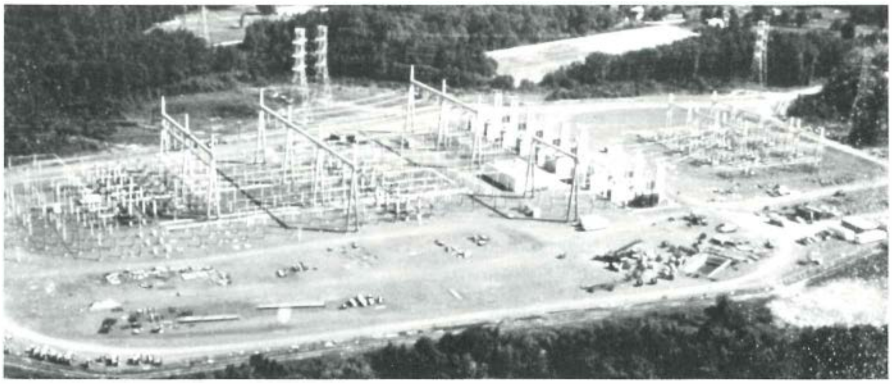
**3.** *Station Computer, I have opened Breakers B and C. The breakers operated correctly.*

**4.** *Head Office, we had a fault current and failure of Breaker A. Breakers B and C were tripped. The fault current has been taken care of, but investigation of the breaker failure is still needed.*



## Demonstration at Deans

In one of several EPRI/utility-sponsored demonstrations, Public Service Electric & Gas is testing a fully integrated Westinghouse protection system at its Deans substation, with a compatible stand-alone protective relay terminal from General Electric soon to be added. The new technology is currently being demonstrated in an open-loop (monitor only) mode but will eventually phase into full operation, including activation of the protection equipment.



nication between the protection clusters and the data acquisition units distributed throughout a switchyard is provided by optical-fiber links. Glass or plastic fibers, easier to install than heavy wire cables, provide less-expensive installation because one fiber cable can replace a number of wire cables. The fiber links also provide electrical isolation between units and immunity to interference from the electromagnetic fields found near high-voltage equipment.

### Precision and flexibility

Compared with conventional substation control and protection equipment, the new integrated system offers several advantages, including greater precision and stability. Each time the system obtains voltage, current, and equipment status data, signals are received from all parts of the switchyard at virtually the same instant (plus or minus 25 microseconds). By sampling such data 16 times per cycle, the system compiles a continuous record for the substation as a whole and can react to emergencies more quickly on the basis of more information.

The digital system offers increased availability, for example, when dealing with system faults. An internal fault occurs on a transmission line being protected by the system, and an external fault occurs on some other transmission line in the utility network. Given today's highly interconnected power grids, both kinds of fault are likely to cause a sudden power surge that would be detected by protection equipment. The correct response for such equipment is to open circuit breakers for an internal fault—thus isolating the damaged line from the rest of the system—but to keep them closed for an external fault. Both the conventional and the new digital protection equipment discriminate between the two types of fault by processing current and voltage values at both ends of a given line and making comparisons of the processed information. In this way they can determine whether the fault lies between them or on some external line. Once breakers have been correctly opened, they are often required to reclose automatically once a fault has been cleared. (In the case of a fault caused by lightning, such clearing may occur within fractions of a second.)

Conventional systems have individual relay devices dedicated to opening and reclosing particular breakers. These devices must be set, checked, and maintained periodically during on-site visits by service personnel. The digital equipment, however, is self-checking, and its response settings can be made remotely by using the built-in communications link. If a circuit board were to fail in one of the microprocessors, for example, for many types of failure the system could alert the central office with a very precise message on an operator's console, such as, "Replace board 17 of bus protection cluster."

One of the important factors impeding more-intensive use of power systems is the lack of detailed, accurate data concerning network behavior during faults. Collecting such data with conventional systems requires adding yet another separate piece of equipment, whereas the integrated systems send sequence-of-events messages automatically to remote operators after a fault and can then provide detailed oscillographic data on request. Such information will provide utilities with a more complete understanding of how their particular systems respond to disturbances.

Automatic fault location also offers utilities a potential cost saving in maintenance. Suppose lightning strikes a transmission line tower in a remote location, causing a current-to-ground fault on one line and possibly damaging an insulator. The fault could be cleared quickly, but doubts would remain about how long the insulator might remain functional. Ordinarily, a utility might send a helicopter crew along the line looking for damage, possibly a considerable time after the event. By locating the fault within a mile or so, the new substation control system would enable a maintenance crew to go directly to the few towers that might have received the lightning strike.

Under EPRI sponsorship, Westinghouse Electric has developed both fully integrated and stand-alone protection systems, and General Electric has developed a compatible stand-alone system. The system is being evaluated by Public Service Electric & Gas (PSE&G). Because of the modularity and compatibility of this equipment, utilities will have great flexibility in adding automated systems to either new or existing substations. "EPRI has committed nearly $10 million and a decade of engineering support to substation automation," says Stig Nilsson, program manager for transmission substations. "I think we are very close to commercialization of these systems, and I'm particularly pleased by the number of utilities wishing to participate in demonstration projects. Without EPRI's help, such systems would have evolved more slowly and in a variety of directions. Our participation brought utility interest to bear on getting systems that would adhere to accepted industry standards for reliability and communication system compatibility."

## Demonstrations

The first demonstration of the new technology began in 1984 under EPRI sponsorship at PSE&G. Since that time, two stand-alone terminals—one from each of the manufacturers involved in the previous development work—have been operating in an open-loop demonstration at PSE&G's Branchburg substation. (In this mode, the terminals monitor inputs from a 500-kV transmission line but do not actually operate any breakers.) Open-loop demonstration of a fully integrated Westinghouse system began recently at the Deans substation, where a stand-alone General Electric terminal has also been delivered. This unit is expected to be integrated with the Westinghouse system during the first half of 1988.

This demonstration program is divided into four phases: field acceptance tests, open-loop monitoring activity, staged fault tests, and phase-in to full operation. During the work carried out so far at Branchburg, the terminals have sensed and correctly responded to all faults on the PSE&G system—signaling protective action for the one internal fault that occurred on its own line, while ignoring numerous external faults.

"Our senior management has been very supportive of what we're doing. We see this as the direction the industry will go," says Howard Petrie, assistant chief controls and electrical engineer at PSE&G. "EPRI did an excellent job coordinating the development work, especially in ensuring equipment compatibility, which is vital to a utility."

Additional EPRI-sponsored demonstration programs are also getting under way at Northern States Power, Philadelphia Electric, and Tennessee Valley Authority. Empire State Electric Energy Research has funded additional research on the basic EPRI design and made upgraded terminals available for its own demonstration projects. One such system is now operating in an open-loop demonstration on a major interconnection between Rochester Gas and Electric and Niagara Mohawk Power. Another system is being installed on an underground cable of Consolidated Edison, serving New York City.

## Future prospects

Because all the functions of the new systems are controlled by software, they can easily be modified with minimal hardware changes. As a result, utilities will be able to add new functions and tailor substation control and protection to meet their specific needs. Several EPRI-developed monitoring devices for incipient fault detection, for example, could be attached with only minor adaptations in the control system. Such devices include partial discharge detectors for transformer monitoring and gas density monitors for gas-insulated substation equipment.

"There's virtually no substation monitoring or control function that couldn't be included," says Project Manager Larry Mankoff. "We're just beginning to explore the possibilities of this technology. Already it's less expensive than conventional devices, but the biggest potential saving is likely to come in long-term avoidance of capital costs for new lines and transformers."

Mankoff explains that at present, ratings for such power equipment are often set on the basis of worst-case analysis. The amount of current that can be carried by a transmission line, for example, may be limited by air temperature—a line is more likely to overheat on a hot day. By using an actual line-temperature monitor attached to an integrated substation control system or an accurate model, current could safely be increased above normal rating levels during periods of unusually large demand.

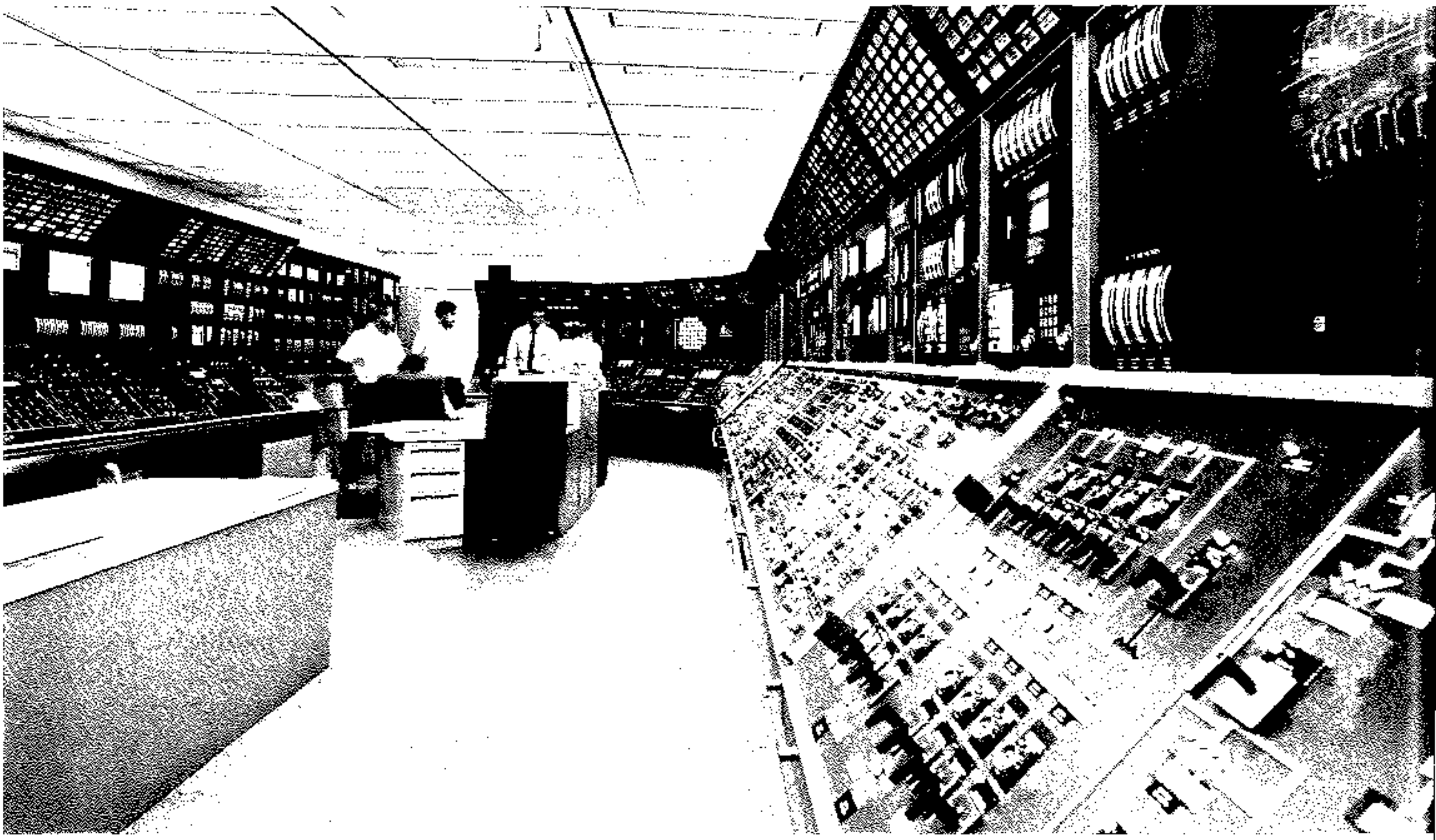
Having fostered development of the technology and encouraged equipment compatibility among the leading vendors, EPRI is now focusing on bringing substation automation into full commercial use. In addition to sponsoring some demonstration projects and assisting in others, the Institute has formed a utility users group for the exchange of information on system operations. The group, which meets three times a year, consists of utilities that have either installed the new equipment or placed orders for it.

Although few new substations or transmission lines are now being added to utility networks, the need for both is expected to increase over the next few years as wheeling of power from one part of the country to another continues to grow. "Utilities may not replace existing analog equipment with the new digital systems," says Mankoff, "but as the demand for new lines and substations rises, I expect these highly automated systems will become the technology of choice." ■

This article was written by John Douglas, science writer. Technical background information was provided by Narain Hingorani, Stig Nilsson, and Larry Mankoff, Electrical Systems Division.

# Simulators: Tough Training for Top Operators

SIMULATED



When a steam generator tube ruptured at Virginia Power's North Anna station (Unit 1) on the morning of July 15, 1987, the operators on duty knew exactly what to do. Within five minutes of the first indications of the rupture, the operators had manually tripped Unit 1 and were on their way to isolating the failed tube and bringing the plant to a safe, cold shutdown. Since there have been only six steam generator tube failures in the history of commercial nuclear power operations around the world, it might be suprising to learn that all the North Anna operators had successfully handled such incidents dozens of times before.

"Granted, during 19 years of duty on U.S. Navy and civilian reactors I had never seen an *actual* tube rupture before," says Tom Porter, assistant shift supervisor at North Anna during the incident. "But, I had seen the procedure for responding to tube rupture performed many times on our plant simulator."

Full-scale simulators that allow nuclear reactor operators to learn and practice normal, abnormal, and emergency operating procedures in a realistic setting have become fixtures in the United States nuclear power industry. These huge, $10 million–$15 million systems combine high-speed computers with nearly exact, full-scale replicas of power plant control rooms, providing utilities with an unparalleled tool for operator training. Simulators allow operators to train on an interactive system that offers the authentic

**Full-scale control room simulators, virtual duplicates of the real things, have become an essential part of nuclear plant operator training. Now researchers are using the simulator as a laboratory for studying equipment, procedures, and modes of human performance.**

ACTUAL

look and feel of the power plant's controls, as well as accurate, real-time feedback on the results of their actions. As the centerpiece of rigorous new training programs that have been developed and implemented in the industry since the TMI-2 accident in 1979, the plant simulator has become a focal point for operational excellence at many utilities and a symbol of operator professionalism and pride.

While helping to transform the nature of operator training in the nuclear power industry, the plant simulator has also emerged as a valuable analytic tool. By monitoring training sessions or temporarily dedicating a simulator to laboratory experiments, utilities can gauge the effectiveness of new control room equipment, validate new procedures, and conduct research on operator reliability for use in probabilistic risk assessments (PRAs) and evaluation of design alternatives. "The plant simulator can enhance the safety and reliability of nuclear power plants in many different ways," says David Worledge, manager of EPRI's Risk Assessment Program. "Simulator training can reduce scrams and accidents by improving the proficiency of the operator, and it can also provide us with important insights into larger questions about the human interface in the nuclear plant control room and the reliability of the operator."

## Evolution of the technology

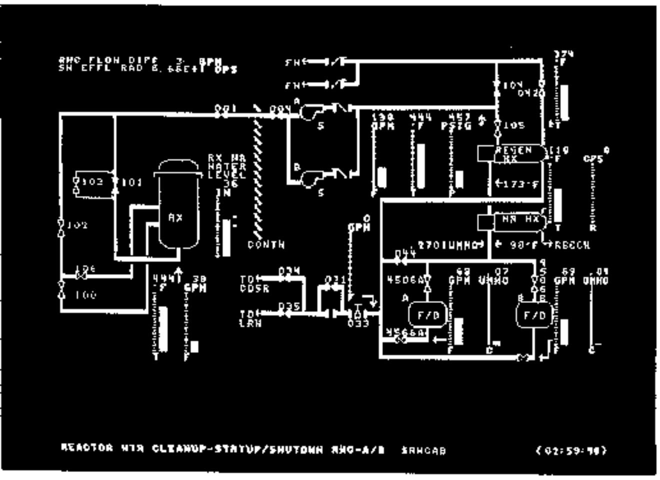
As plant simulators have become more capable and their value more apparent to utilities and regulators, the number of simulators in use in the industry has grown from only 4 generic, vendor-owned simulators in existence in the early 1970s to 10 vendor simulators and nearly 70 utility-owned systems in service today. Most utility reactors or reactor complexes now have their own simulators that model individual control rooms and are programmed with data on conditions and responses to operator actions that are specific to each plant. In addition, these simulators can be continually reprogrammed to account for plant modifications and new technical data on plant conditions that may become available.

Different forces have helped drive the acceptance of simulator technology by the nuclear power industry, beginning with a shortage of qualified reactor operators that was first felt by utilities in the early 1970s. "Before the development of simulators, operators trained somewhat like surgeons, looking over the shoulders of other operators," says Jean-Pierre Sursock, manager of EPRI's Safety Control and Testing Program. "Sometimes small test reactors or units that were shut down or operating at low power were used for training, but these were not always available and couldn't offer practice on abnormal conditions or emergencies. With so many new and different plants coming on-line in the 1970s, utilities began to look for a better way to train the large numbers of operators that they were going to need."

During the 1970s plant simulators evolved from generic tools for teaching principles of reactor operation to systems capable of modeling actual plant conditions in real time with great detail and accuracy. These changes followed from advances in computer technology that increased processing speed and reduced the size and cost of hardware, as well as from the greater availability of plant technical data for simulator programming that accrued as more plants came on-line. Generic vendor-owned training simulators were developed first, followed by

## Simulator Training in Action

The plant-specific simulator at Pennsylvania Power & Light's Susquehanna plant is the anchor for a rigorous program of operator training that has helped the two-unit BWR achieve one of the outstanding operating records in the industry. As a central component of both initial and ongoing requalification training for operators, the Susquehanna simulator includes a state-of-the-art 32-bit computer and a nearly exact replica of the plant's control rooms. Operating crews learn from classroom instruction, hands-on practice with the controls, and instructive dialogue with trainers and training supervisors, who are themselves licensed operators.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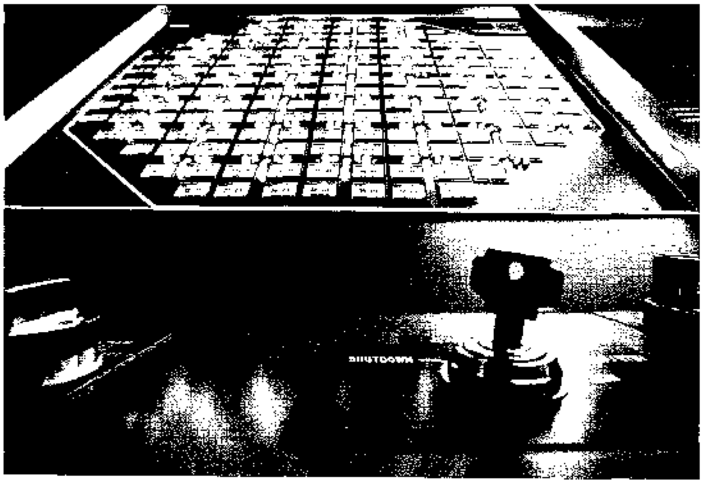
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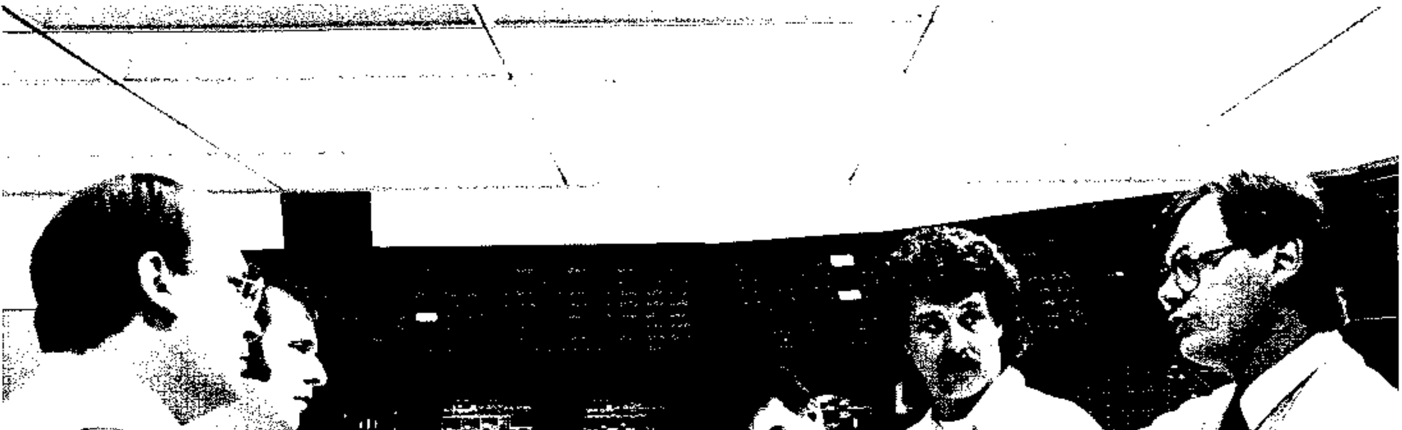


vendor-owned simulators that referenced particular plant designs, and then, eventually, by utility orders for plant-specific systems. By the late 1970s, nearly a dozen pioneering utilities had committed to plant-specific systems.

The industry seemed on its way to gradually adopting simulator training, a progression that was accelerated by the 1979 accident at TMI-2. Operator error was identified as an important contributing factor to the accident, which was followed by a call from NRC and several independent study groups for examination and improvement of operator training across the industry. The resulting changes in regulations established a new set of qualifications for operators, including the requirement that they pass simulator tests as part of their initial licensing exams and undergo requalification training on a regular schedule. The new regulations, together with steadily improving computer technology and a growing awareness in the industry of the importance of operator training in ensuring reactor safety, motivated dozens of other utilities to order plant-specific simulators after TMI-2 and to develop training programs to go with them.

Formation of the Institute for Nuclear Power Operations (INPO) by U.S. nuclear utilities in 1980 has also bolstered and improved simulator training across the industry. As part of its program to promote improved safety and reliability in U.S. nuclear power plants, INPO published a widely used guideline to help utilities design and implement simulator training programs. Following this guideline, utilities can be assured that their simulator training programs meet the criteria established in ANS 3.5, a standards document approved by NRC. INPO also reviews and evaluates training programs as part of the periodic technical evaluations it conducts at the nuclear plants of its member utilities.

In addition, in 1985 INPO formed the National Academy for Nuclear Training, an organization that evaluates and grants accreditation to utility training and qualification programs, including operator training both in the classroom and on plant simulators. To grant and renew accreditation, technical experts from the academy regularly visit member utilities to evaluate simulator training programs and make recommendations for changes in their format and scope. "We have a cooperative and instructive relationship with the INPO staff, and they've made some helpful suggestions that we've worked into our training," says Ray Raguse, training manager at Commonwealth Edison's LaSalle plant, an accredited member of the National Academy. "When you're committed to a high standard of excellence in training and operator performance, you need to be constantly interested in improving your program."

As they work with INPO on operator training, many utilities are exploring recent advances in computer technology that can enhance the capabilities of their plant simulators. Equipped with the latest generation of high-speed 32-bit computers, today's most capable simulators can model virtually any plant condition or malfunction that can exist physically. In addition, the most functionally powerful modern systems can model transients as they develop over long periods of time and as they are influenced by operator interventions. This gives operators the chance to gain control of a simulated accident over a period of several hours, just as they might do in a real-world situation.

The state of the art in simulator technology also includes a high level of detail in the physical modeling of the control room. Most plant simulators currently are equipped with replicas of control panels that stand behind or apart from main panels, telephone hookups to technical support centers and emergency response facilities, and models of plant CRT-equipped systems, such as the safety parameter display system (SPDS). During a simulator training session, operators often make the same kinds of phone calls they would during a real transient, requesting consultation from plant managers or making requests for equipment checks or adjustments on plant systems not under automatic surveillance or control.

## Training for excellence

For the reactor operators, senior reactor operators, shift supervisors, and shift technical advisers who compose a control room crew, the plant simulator figures as an important, although by no means the sole, component of their initial and requalification training. Operators at Pacific Gas and Electric's Diablo Canyon plant, for one example, prepare for their initial licensing exams in a 56-week course that consists of classroom training, instructional tours of the plant, observation of the actual control room, and simulator training on a wide range of normal and abnormal operating conditions. This course prepares the operator candidate for the NRC's three-part licensing exam, which includes oral questions and answers during a plant walk-through, a written examination, and testing on a simulator. Operators who receive their licenses will then dedicate one week out of six for the remainder of their careers to requalification training, including nine hours of simulator practice during each requalification week.

A typical requalification session on the simulator will include a mix of different exercises. These range from practice on normal operating procedures, such as plant startups and power reductions, to preparation for unlikely emergency situations, such as station blackouts or breaks in large pipes and loss of coolant. During requalification, most utilities design simulator exercises to parallel classroom instruction given during the same day or week. Following a classroom review on a particular accident or category of accidents, the operators move to the simulator for hands-on practice in the lessons learned. The operators know what type of procedure they will be practicing but are usually not prebriefed on the particular developments (failures of specific pumps or valves, for example) that they will be asked to handle as the event unfolds on the simulator. This training structure helps operators develop a true understanding of the principles at work in the reactor, while also preparing for the many different eventualities that may occur within a category of accidents.

The interactive features of plant simulators provide some unique training opportunities. On most systems the trainer can speed up a transient or accident sequence so operators can watch it develop, freeze the sequence at a critical point to discuss the control room indi-

## Practice Makes Perfect

During initial and requalification training, operators practice a wide scope of normal, abnormal, and emergency procedures on the plant simulator, sharpening their skills and establishing the patterns of communication that they will count on in the control room. Typical of the challenges served up in simulator training is the one cited in simplified form below, where operators must close a stuck-open BWR safety relief valve (SRV) in two minutes or else scram the reactor to avoid operation without a fully functional safety system.

**0:00 minutes.** An acoustic alarm in the simulator rings, just as it would in the control room, indicating that the SRV is stuck open.

**0:00–0:20.** Immediately responding to the alarm, operators follow off-normal procedures and check the valve tail pipe temperatures and main power indicators to confirm that the valve is indeed open.

**0:20–0:50.** The valve is confirmed as stuck open. In accordance with procedures, one of the licensed operators attempts to automatically close, or cycle, the valve.

**0:45–0:50.** The troublesome valve, however, does not respond to the controls. The shift supervisor orders the operators to prepare for a reactor scram.

**0:50–1:45.** In preparation for the scram, inhouse power loads are transferred to off-site. Oil pumps are started to lubricate the main turbine. One of the crew telephones the utility's power control center to inform distribution personnel that the plant is coming off-line.

**1:50.** The shift supervisor orders a manual scram of the reactor. The reactor is scrammed, and the crew begin actions to bring the plant to a cold shutdown over the next several hours.

# Methodology for Simulator Qualification

In April of this year NRC announced that as of 1992 utilities will be required to qualify their simulators as part of the operator qualification process. Anticipating these regulatory changes and responding to utility needs for guidance on the technical evaluation of their simulators, in 1985 EPRI completed the *Analytic Simulator Qualification Methodology* (NP-4243).

Using the methodology, utilities evaluate their simulators on the basis of their training objectives. In a step-by-step fashion, the utility demonstrates the accuracy or fidelity of the simulator in modeling control room functions and plant conditions. The utility also demonstrates that the simulator has the necessary range of capabilities or scope to model the many different normal, abnormal, and emergency procedures used in a training program. The overall process can establish that a simulator meets the criteria for fidelity and scope outlined in ANS 3.5, an NRC-approved standards document.

The methodology guides utilities in the use of both plant data and engineering codes, such as the EPRI-developed RETRAN, to establish simulator fidelity. Because actual plant data on conditions during hypothetical accident scenarios are not always available, computerized tools like RETRAN can play an important role in the development, validation, and qualification of simulator programs for modeling accidents. □

cators and correct procedural response, and then replay the entire sequence with the operators now encouraged to take action at the appropriate time. If operators make diagnostic or procedural errors at any point in a training session, they can later examine recorded data or replay the simulated plant response to identify their errors and learn from their mistakes.

In other cases, trainers may call a special lab session on the simulator to familiarize operators with a plant modification or emerging operational issue. In general, simulator training sessions usually proceed somewhat like the making of a movie, including both intense periods of operator activity and frequent interruptions from a trainer to discuss what has occurred and what will happen next.

Communication is an important element in simulator training: operators learn to work together as a team, reading out loud from control panel instruments and receiving oral orders to follow detailed procedures. A senior member of the crew typically takes the lead role during a transient or emergency, reading from documented procedures that are based on plant indicators or symptoms. Following the completion of each step or series of steps in the procedures, the reader waits for word from the other operators on the plant's response before identifying and ordering the next step. The plant simulator gives operators the chance to practice this process and develop the communication skills they need to effectively function as a team.

## The simulator as laboratory

Lessons learned from use of the plant simulator can benefit utilities in ways that go beyond improvements in the skills of individual operators and crews. The simulator can also function as a laboratory for safely testing new procedures, new control room equipment, and that most complex of all systems employed in a nuclear power plant—the human.

The question of human reliability and its part in determining the risks of reactor operation looms especially large in the aftermath of the core-disruptive accident at TMI-2 and the far more destructive reactivity accident at Chernobyl, both of which included operator error as contributing causes.

Now that lessons learned from TMI-2 have been incorporated into improved training and operations across the U.S. nuclear power industry, researchers in an EPRI-sponsored series of operator reliability experiments (ORE) are using plant simulators to quantify operator performance and develop more-realistic models of human reliability.

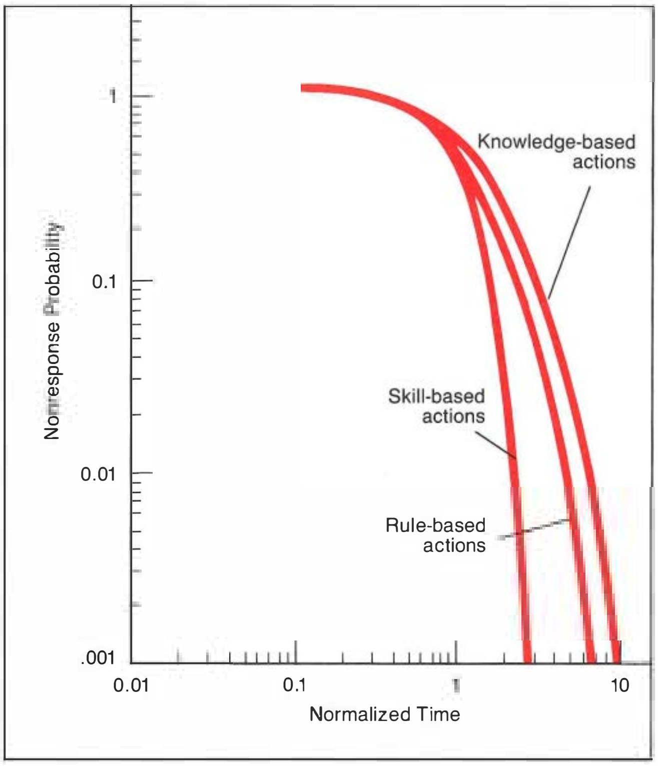
During ORE, researchers are keeping score during requalification training at six reactor sites in the United States and two training facilities in France, measuring operator performance in the realistic settings that plant-specific simulators provide. In the course of ORE, project investigators will note the degree of success of operator crews in bringing a range of simulated accidents under control within predetermined time intervals. Scientists will then use these data points to improve human reliability computer models, which in turn will be used in PRAs and in the design of future nuclear power plants.

An important goal of ORE is to support the development of PRAs that will account for both the positive and negative roles that operators are likely to play in various accident sequences. "In widely used risk assessments, such as WASH-1400, the operator is considered largely in terms of the probability of his making a mistake and adding to plant risks," explains David Worledge. "Through ORE we hope to build models that will also allow for the probability that operators will take effective action to avert core damage during an accident."

In addition to making quantitative measurements of operator performance, researchers in the ORE project will observe and document such factors as the patterns of communication in the control room, the use of specific types of dis-

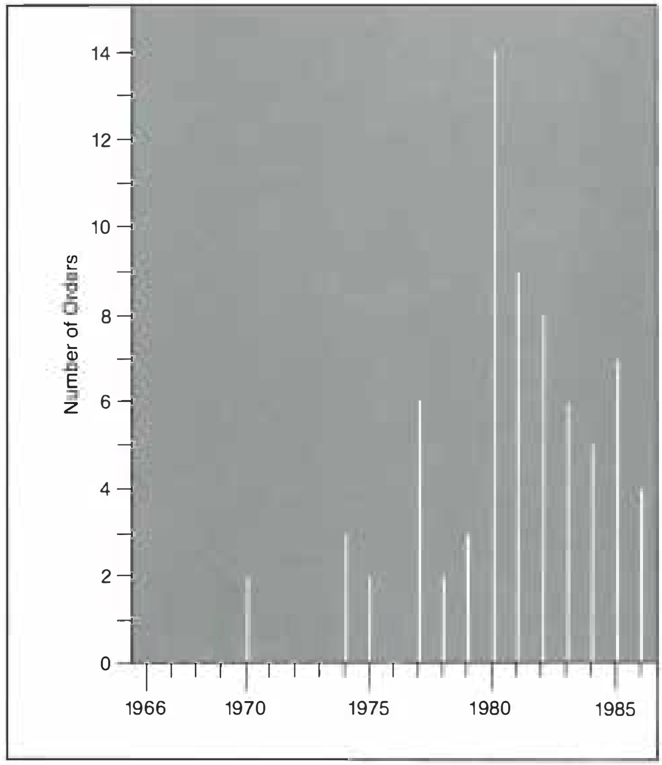
## The Value of Practice

Data gathered in EPRI's Operator Reliability Experiments show that operators performing frequently practiced, or skill-based, actions are quickest in correctly responding to accident conditions. These data suggest that some utilities might improve human reliability factors by putting a greater emphasis on skill-based training and procedures.




## Simulator Training Takes Off

Orders for full-scale nuclear plant simulators by utilities and nuclear steam supply system vendors increased rapidly following the TMI-2 accident in 1979, when new regulations made simulator training part of the operator qualification process. Today there are 10 vendor-owned systems and nearly 70 plant-specific utility systems in service or on order.




plays and instruments available to the operators, and the leadership style of crew members. Having been analyzed and correlated to operator performance on the simulators, these data are already aiding utilities in refining their training programs, their operating procedures, and their control room designs.

In a related project Taiwan Power personnel, under a contract with EPRI, are using a training simulator in Taiwan to investigate the impact on operator performance of a new display system that uses principles of artificial intelligence to help operators track procedures during an accident. "The simulator helps us find out whether this system is going to be a great help to operators or make their job more difficult," says David Cain, an EPRI project manager who specializes in artificial intelligence. "The realistic, real-time setting in the simulator helps us consider the human factors that ultimately determine the value of a new technology."

Overall, plant simulators functioning as tools for both training and research are contributing to an improved human-machine interface in U.S. nuclear power plants, an increasingly more professional and proficient community of plant operators, and steadily rising standards of safety and reliability. Just as the cooling tower came to serve as a symbol of nuclear power in the public's mind in the 1960s and 1970s, the plant simulator may come to symbolize a viable nuclear option in the era of high technology. ■

**Further reading**


Carl Babb. "Preparation Pays Off." *The Nuclear Professional*. Winter/Spring 1988.

J. B. Gonsalves and J. F. Proctor. "Nuclear Plant Simulators: The Past and the Present." *Nuclear News*. June 1987.

Gregg M. Taylor. "A Reactor Operator at Diablo Canyon." *Nuclear News*. September 1987.

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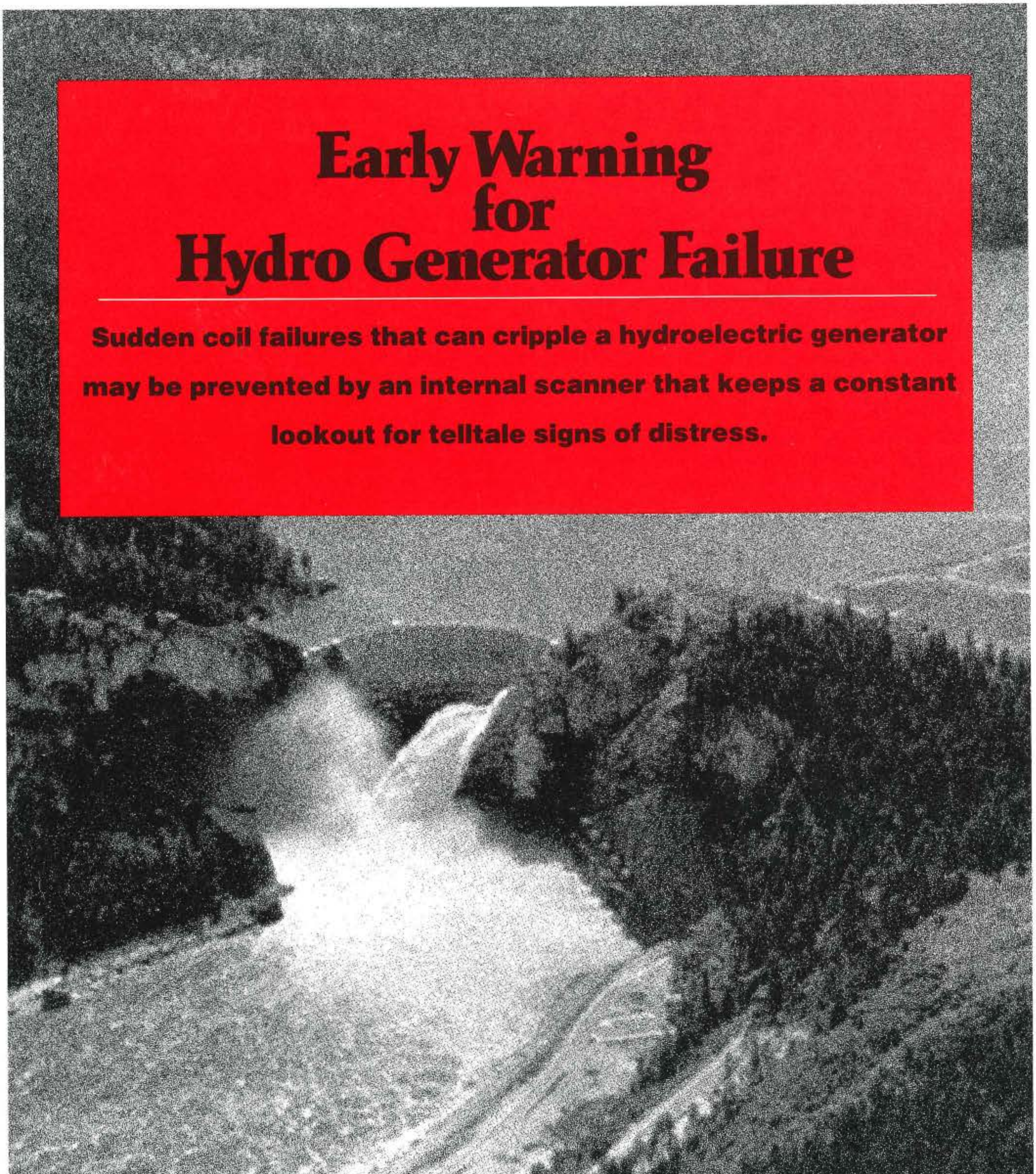
This article was written by Jon Cohen, science writer. Technical background information was provided by David Worledge and Jean-Pierre Sursock, Nuclear Power Division.

# Early Warning for Hydro Generator Failure

**Sudden coil failures that can cripple a hydroelectric generator may be prevented by an internal scanner that keeps a constant lookout for telltale signs of distress.**



Although hydroelectric power plants are exceptionally reliable, with an average 95 percent availability, their huge generators have become increasingly susceptible to sudden catastrophic failure. A leading cause of such failure is the progressive deterioration of insulation in the stator windings, which eventually results in melting of the copper coils of the windings or the iron cores. This damage may take six months or more to repair at a cost of several million dollars, including purchase of replacement power during the unanticipated outage.

Most sudden failures could be avoided by monitoring the temperature and other physical characteristics of stator windings, but such measurements are difficult to make. The main problem is sheer size: the stator of a hydroelectric generator may be over 30 feet across and contain more than 500 individual coils in the stator core. Placing direct-contact thermal probes in each coil would be prohibitively expensive. Monitors are available to detect the presence in a generator of telltale radio-frequency emissions that accompany some types of failure, but these have not been able to pinpoint accurately the location of a distressed region or to warn of all serious heat-producing conditions.

An alternative strategy would be to mount a monitor on the generator rotor, where it could gather data from the whole stator surface during each revolution. Such an approach presents some formidable engineering challenges, however, and previous attempts to develop rotor-mounted monitors have been largely unsuccessful. Among the technical challenges are severe mechanical stress on monitor components; communication of data and commands between the swiftly moving sensor array and a remote operator; and, in some ways most difficult of all, delivery of power to the monitor assembly.

All these hurdles have now been overcome in a rotor scanner developed with EPRI funding by Spectra Technology, Inc., of Bellevue, Washington. The first prototype unit was installed last year in a 167-MVA generator owned by Seattle City Light, where it has already helped avoid a failure that would probably have occurred during last spring's peak run-off period.

"This instrument gave us the surveillance that enabled us to continue full-time operations at reduced rating," says Bob Youngs, chief electrical engineer at Seattle City Light, "thereby forestalling an expensive shutdown during the generator's period of maximum revenue."

## Warnings of failure

Although the ultimate breakdown may occur rapidly and dramatically, the underlying failure processes in stator windings usually evolve gradually over a period that can range from days to months. During this period, the insidious deterioration is usually accompanied by warning signs that can be used to locate damage and monitor its progress.

One reason for the increasing number of failures in recent years has been a change in the type of insulation around conductors in stator coils. Traditionally this insulation was mica held together in an asphalt binding medium, which was relatively forgiving of thermal expansion or mechanical vibrations. The asphalt, however, had a relatively low melting temperature and bond strength. By substituting modern epoxy to hold the mica, designers were able to pack copper conductors more densely into the windings and also operate them at higher temperatures.

Although this development improved the electrical performance of generators, the new coils were more brittle and thus more susceptible to mechanical stress. If a coil is installed loosely in its slot in the stator—and proper installation is more difficult than with the older coils—it can begin to vibrate and abrade the surrounding insulation. In addition, the copper conductors, iron core, and epoxy-mica insulation of a winding all expand and contract to different degrees when heated and cooled, which also eventually tends to loosen the coils in the slot.

Once looseness occurs, the transfer of heat out of a coil is impaired, and small voids may develop in the insulation. The high-voltage electric fields present in stator coils then create a corona discharge across the voids, releasing ozone. This ozone, aided by the rising temperature, chemically attacks the insulation and causes further degradation. Also, shorted or broken conductor strands may begin to arc. Eventually the insulation breaks down, resulting in a short circuit and melting of the coil.

The various stages of winding deterioration can be detected by the new rotor monitor. The first warning sign would probably be acoustic, as a loose coil vibrates inside its slot. Next would come radio-frequency emissions from the corona discharge and broken-strand arcing. Finally, a marked increase in temperature would warn of impending failure in the coil.

Another type of failure, marked only by rising temperature, can occur in the iron core into which the coils are wound. The stator core consists of laminated iron sheets coated with a thin layer of insulating material. Alternating magnetic fields induce currents in these sheets. If the insulation between adjacent sheets breaks down, the currents flowing between laminations may become large enough to melt the iron or heat the coils locally, leading to insulation failure.

Since heat is produced in the iron core by the magnetic field coming from the rotor even when no current is flowing in the stator coils, it is possible to distinguish between incipient core failure and coil failure. The indication of localized hot spot temperatures when a generator is started up, even before it is connected to a load, warns of a core problem. Abnormal temperature rises that are proportional to the load and that are accompanied by more noise and radio-frequency emissions probably indicate incipient coil failure.

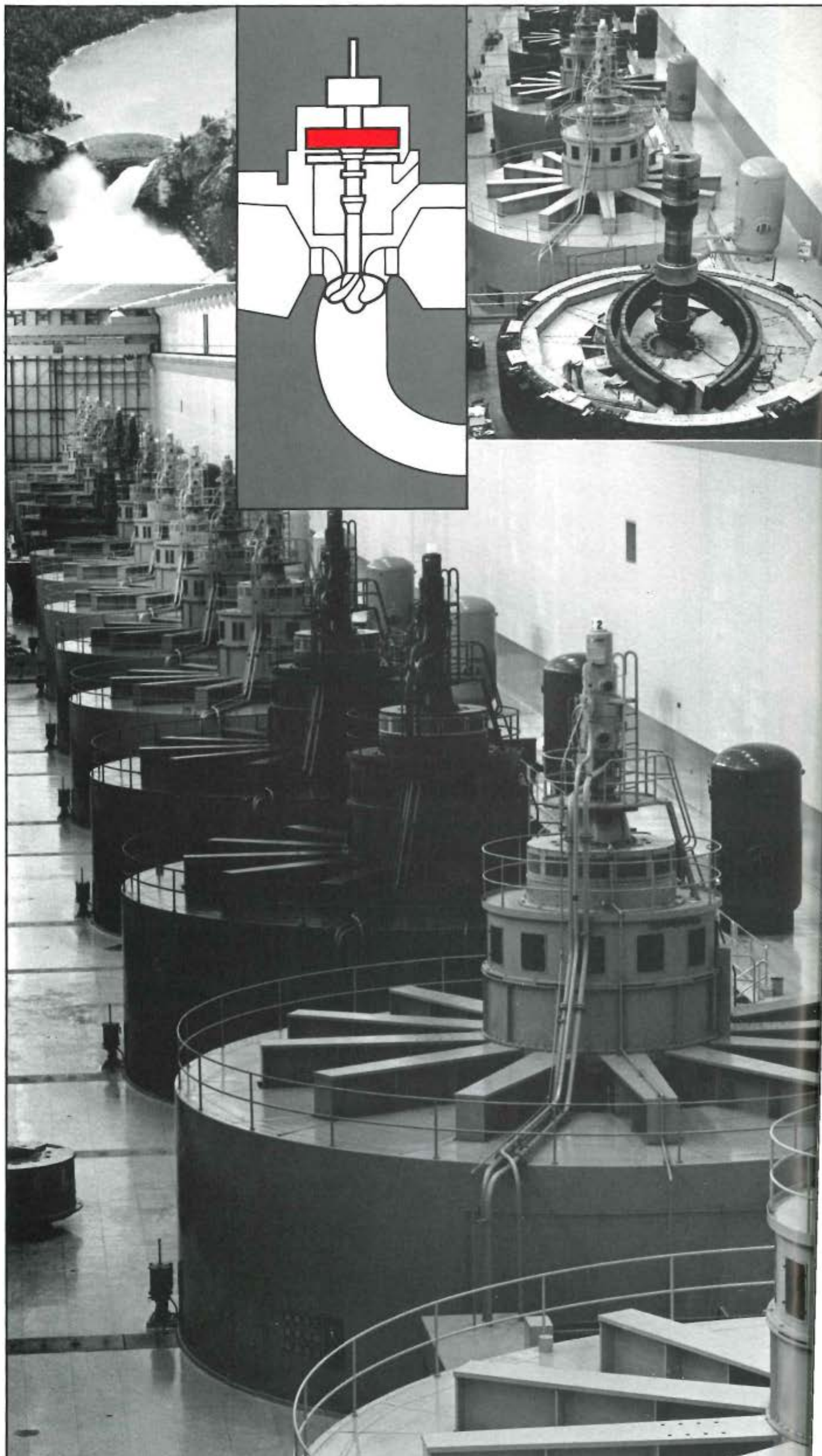
## Data and power

"When EPRI got involved in this effort back in 1983, researchers had been wanting to develop a rotating scanning monitor for several years," says Project Manager James Edmonds, "but no one had been able to get the data off the rotor continuously and keep the device reliable. Spectra Technology started with a basic design developed by the Bureau of Reclamation but used LEDs (light emitting diodes) on the rotor that do a fast data dump when they're in alignment with a set of photodiodes (tiny light receptors) on the stator. It is an exceptional piece of engineering."

The monitor contains 54 individual sensors, and data from each are transmitted across the optical link in pulses during the moment of time that the LEDs and the photodiodes are in alignment. Although the sensors operate continuously, only one at a time is chosen for data transmission. In addition, a set of LEDs on the stator sends instructions and a timing pulse to the monitor. One early concern about such an optical data transmission system, according to Edmonds, was that the passage of light might be obscured by an accumulation of dirt on the LEDs and photodiodes. A particularly important source of dust in these generators is the brake pads used to slow the rotor during shutdowns. In practice, however, turbulence and occasional cleaning have kept dirt from coating the optical components.

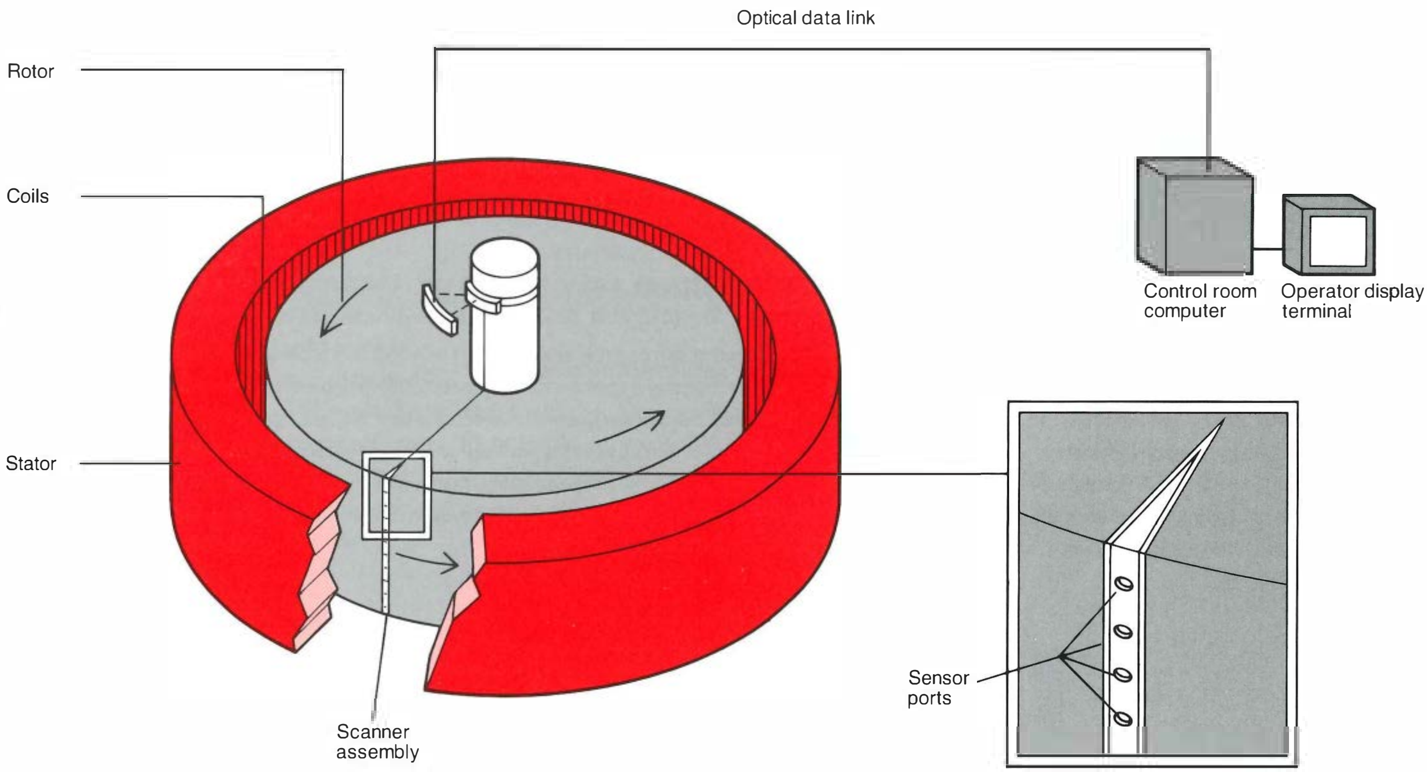
Data received by the photodiodes are transmitted to a control room computer by a fiber-optic link. The use of optical fibers prevents interference by strong electromagnetic fields in the generator

Boundary Dam | Turbine cutaway | Turbine hall



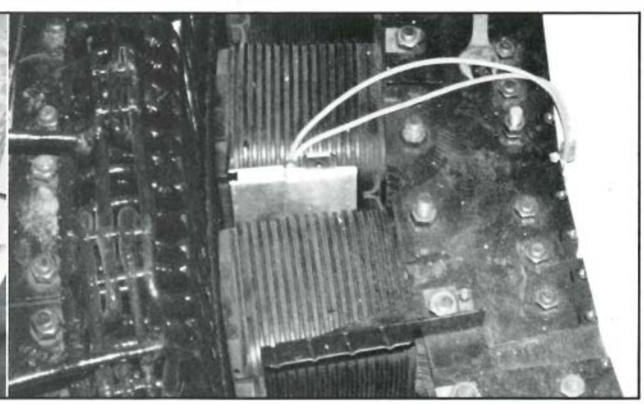
# The Rotor-Mounted Scanner at Work

The huge turbine generators in hydroelectric dams can fail suddenly if progressive damage to the generator's stator windings goes undetected. The rotor-mounted scanner was designed to monitor the generator stator to detect early symptoms of failure and pinpoint their source. The scanner is a long wedge-shaped assembly installed at the perimeter of the generator rotor. As it sweeps across the stator surface, its 54 individual sensors gather acoustic, thermal, and electrical data that warn of stator damage and pinpoint the location of trouble spots to within a few centimeters. Sensor data travel off the spinning rotor as pulses of light and are then sent to a computer for processing and display. The prototype rotor-mounted scanner proved its worth in the Boundary Dam powerhouse shortly after it was installed in a generator with known stator damage. Data from the scanner allowed plant officials to continue full-time operation at a reduced power setting that wouldn't cause further damage to the stator.





Scanner installation


Generator with scanner in place

environment. Data are then processed by a minicomputer and displayed to an operator numerically and graphically on a color terminal. The computer analyzes the data, controls the monitor, and stores a record of data trends on a hard disk. Remote access for monitor control and data retrieval can also be provided by telephone lines and modems.

Another crucial problem was how to provide power to the monitor. In the first prototype, a magneto generator was used (similar in principle to the spark generator in a gasoline-powered lawnmower). Such generators consist of one or more coils of wire in which pulses of electric current are induced as they move past a strong electromagnet. For the first prototype of the scan monitor, 10 induction coils were spaced evenly around the rotor, where they would pass by electromagnets mounted on the stator. Each pulse of current from the coils would then recharge a capacitor bank, which provided energy to the monitor sensors.

A disadvantage of using a magneto power supply for long periods, however, is that its components are subjected to considerable mechanical forces because of the pulses of power. For subsequent prototypes, therefore, Spectra Technology chose to take power directly from the rotor windings. This alternative also presented a significant technical challenge. Voltage in the windings may vary from 50 to 500 volts, depending on the power output of the generator, while the sensor circuits may require a steady potential of only about 15 volts.

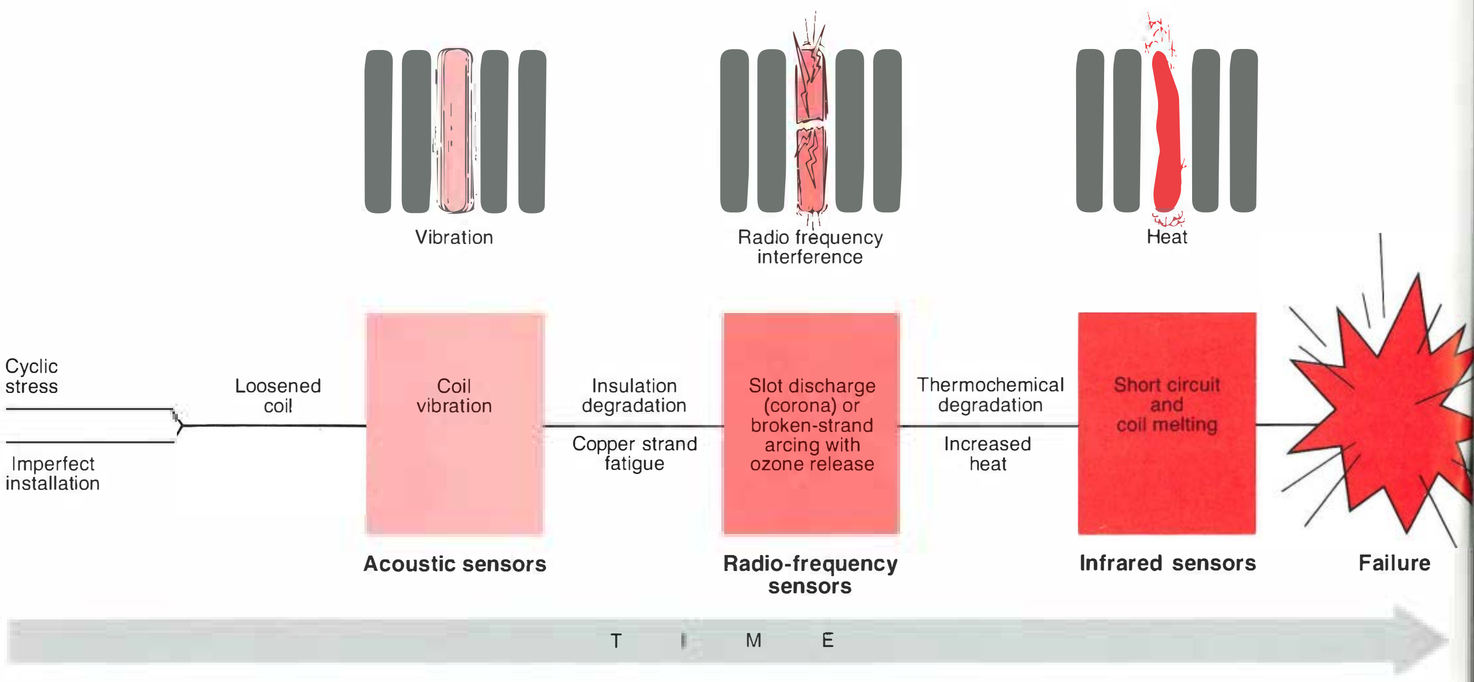
To solve this problem, engineers designed a high-performance voltage regulating circuit for the rotor-mounted scanner, which supplies a constant voltage to the sensor electronics. Specially designed batteries, which are a part of the on-board power supply, allow the monitor to be operated when there is no excitation of the rotor field winding.

### Multiple sensors

The rotor-mounted scanner itself consists of a tall, narrow, enclosed structure (called a bridge) inserted between two poles of the generator rotor. Sensors are

## Tracking the Symptoms of Stator Failure

Failures in generator stator windings are preceded by a chain of events that can begin with a loose coil and end with a generator outage. The rotor-mounted scanner detects the symptoms that accompany each stage of the deterioration process, allowing plant personnel to take corrective action during scheduled shutdowns. In this simplified scenario, the scanner's acoustic sensors detect the first signs of trouble when a loose coil begins to vibrate in its slot. Antennas and amplifiers detect radio-frequency (RF) signals emitted when the vibrating coil wears down its surrounding insulation to cause slot discharge, releasing ozone. The heat and ozone team up to chemically corrode the insulation, causing further damage. Finally, a sharp rise in temperature warns that the insulation has broken down enough to cause a short circuit, coil melting, and imminent failure.



distributed along the vertical axis of this bridge. Because the sensors would be subjected to an unusually severe operating environment—one with a centrifugal force on the order of 80 g and temperatures in excess of 60°C—Spectra Technologies built a generator simulation facility to test the equipment. This facility consisted basically of a temperature-controlled centrifuge in which components could be subjected to accelerated life testing.

Infrared and thermopile sensors installed along the bridge provide thermal monitoring. These sensors can determine the temperature at the surface of the stator circumference to within 1°C, with a vertical resolution in each winding of 12.5 centimeters and a horizontal resolution of 2.54 centimeters.

Condenser microphones attached to earlike horns provide acoustic monitoring. Considerable filtering and computer analysis are needed to distinguish audible signs of coil failure from the deafening background noise in the generator air gap.

Radio-frequency emissions are detected by antennas and amplifiers that can accommodate an exceptionally wide range of signal strengths—from the weak electromagnetic radiation of corona discharges to broken-strand arcing emissions many times more powerful.

Ultrasonic transducers, acting as sonar devices, monitor the air gap between the rotor and stator. This gap is very small compared with the rotor diameter, and the transducers enable operators to detect any gradual shift in the stator core structure.

In addition to these devices, which monitor the operating status of the generator, other sensors have been included that provide information on the scanner itself. Accelerometers, for example, were added as a safety precaution to detect any loosening of the sensor bridge. Voltage monitors measure induced potential along the bridge, while Hall-effect sensors measure external magnetic fields impinging on the bridge.

These additional sensors proved their worth soon after the first prototype was installed. With the generator spinning at rated speed and as rotor field excitation was increased, the various devices of the monitor ceased operation, one by one. Analysis of the Hall-effect data showed that magnetic fields penetrating the scanner bridge were overwhelming tiny transformers supplying power to individual sensors. Spectra Technology engineers duplicated the effect in their generator simulation facility, then replaced the transformers with capacitors to set voltages for various components.

"They diagnosed the problem in a day and fixed it in a week," recalls Edmonds. "This outstanding example of engineering epitomizes the excellence of work throughout this project."

## Toward commercialization

The first prototype scanner monitor was installed in February 1987, in a generator that Seattle City Light had suspected was nearing failure. Located at the Boundary powerhouse on the Pend Oreille River, in northeast Washington near the Canadian border, the generator is one of four that were commissioned in 1967. Since 1969 these four generators have suffered a number of significant failures.

After the scanner was installed, operators pinpointed a few specific locations in the stator core that were overheating and in danger of failing. They then determined a reduced power level at which the generator could be operated full-time without incurring further damage. At last report, shutdown for extensive generator maintenance has been postponed indefinitely. Only a short outage is now anticipated to repair suspected shorts between laminations.

"They were able not only to avoid another failure but also to defer maintenance and extend the life of the generator," says Edmonds. "News like that travels fast in this industry, and judging from the number of phone calls I've been getting, reaction to the new monitor has been very favorable."

Seattle City Light has ordered a similar scanner for installation on another generator at the Boundary powerhouse. The U.S. Army Corps of Engineers is also participating in the project. A second prototype monitor, which has a number of major changes, will be installed in a generator at the Corps' Lower Granite powerhouse on the Snake River in southeast Washington.

Under EPRI contract, Spectra Technology is now conducting a feasibility study of what will be necessary to bring the scanner monitor into full commercial production. Usually such production involves standardizing the design of a technology and setting up a manufacturing facility. One major obstacle in this case, however, is that most hydroelectric generators are somewhat custom-designed, so the extent to which the monitors can be standardized remains unclear.

Further in the future, EPRI hopes to develop a similar type of monitor for use in turbine generators at fossil fuel power plants. In this case, the major challenge will be to find a suitable place on the much more compact rotor to mount the sensors. In addition, the components will be subjected to even more stress, because turbines rotate up to 3600 rpm—much faster than rotors in hydroelectric generators.

"We are aggressively pursuing various commercialization alternatives," says J C. White, program manager for plant electrical systems and equipment in the Electrical Systems Division. "The rotor scanner satisfies so many critical monitoring requirements that I anticipate it will be installed on most large hydroelectric generators within a few years." ■

This article was written by John Douglas, science writer. Technical background information was provided by James Edmonds and J C. White, Electrical Systems Division.

# TECH TRANSFER NEWS

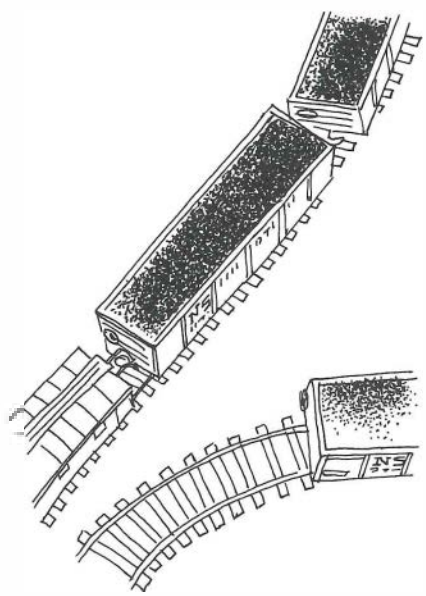
## KCPL Applies Full Range of Fuel Planning Tools

Innovative fuel planning has produced impressive cost savings and ensured system reliability at Kansas City Power & Light (KCPL), a utility that has made good use of an array of software products, data bases, and reports developed by EPRI's Utility Planning Methods Center, Planning and Evaluation Division. Close communication and a strong working relationship between the utility and the Institute have aided KCPL in achieving millions of dollars in annual cost savings over its previously applied strategies for procuring coal and managing inventories.

KCPL has realized several new planning goals in the 1980s, including a 42% reduction in coal inventory levels that was accomplished in 1986 by using the PC-based utility fuel inventory model (UFIM). The software allows planners to evaluate the economic and operating effects of different inventory management options and develop a strategy that best balances the cost of maintaining coal inventories against the costs of running short of the fuel.

Working with the software, KCPL planners calculate inventory trigger levels that serve as gages for determining when to conserve inventories by reducing coal-fired generation or buying additional power. This strategy allows the utility to respond to disruptions in coal supplies while keeping inventory levels low, saving approximately $3 million in annual carrying charges. As a result of this accomplishment and successful applications of UFIM at other utilities, the EPRI software package was nominated for the prestigious Edelman Management Science Award in 1988 and finished second in the balloting among the 30 products selected for nomination from thousands of possible candidates.

"But KCPL's fuel planning goes beyond UFIM," says EPRI Program Manager Howard Mueller, "demonstrating the added value a utility can receive by using all our integrated fuel planning tools in



combination." Since 1986, for example, KCPL has used other EPRI software and related information products to analyze and design the mix of contracts through which it procures coal. This process involves the sequential use of different products, beginning with the PC-based FUELBURN system for forecasting long-range unit generation and fuel burn requirements across the KCPL system. Data produced by FUELBURN are then used for analyses of different contract strategies performed with CONTRACTMIX, another PC-based system. In addition, KCPL planners attend EPRI Fuel Supply Seminars and use several EPRI reports and data bases that provide forecasting information for use with the computer models, including the EFIAS on-line fuel forecast data base, the EPRI Fuel Forecast Review Service, and reports on coal markets and utility fuel choice (RP2369-53) and coal price formation (EA-4971).

Using these products in an integrated fashion, KCPL has designed a diverse and cost-effective contract mix. "The EPRI software and information products have helped us design a portfolio of long-term, short-term, and spot-purchase agreements that minimizes our fuel costs while ensuring a dependable fuel supply for our system and our customers," says Ed Blunk, KCPL Supervisor of Fuel Planning. "This includes the purchase of about 20% of our coal on the spot market, which will save us about $2 million–$3 million over each of the next several years." ■ *EPRI Contact: Howard Mueller (415) 855-2745; Utility Contact: Ed Blunk (816) 556-2324*

## Guidance for Fire-Side Testing

By conducting fire-side tests in their power plant boilers, utilities can diagnose operational problems and select coals that will produce lower busbar electricity costs. Methods for conducting these tests vary widely, however, and utilities have at times faced uncertainty about how to design the best tests for specific coals and plant designs. These problems can be solved with the help of a new resource, *Guidelines for Fireside Testing in Coal-Fired Power Plants* (CS-5552).

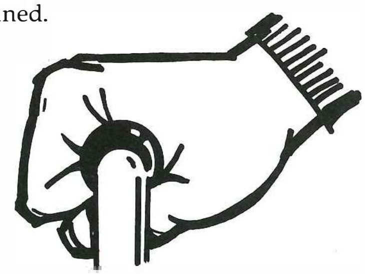
The guidelines provide utilities with a practical, comprehensive manual for planning, conducting, and documenting fire-side test programs on boilers, coal pulverizers, and electrostatic precipitators. It also outlines methods for establishing programs to solve operating problems, such as slagging or excessive quantities of carbon in the ash. Recommended procedures for evaluating 22 operating characteristics (e.g., pulverizer fineness, furnace slagging, and air heater or precipitator efficiency) appear in tabulated form. In addition, the guidelines include a detailed case study of a fireside testing program, as well as information on new and special research-oriented tests.

With the guidelines completed, EPRI now plans to demonstrate their effectiveness in a follow-on project at six host utilities (RP1891-4). The project will obtain utility feedback on the guidelines and suggestions for improvements. The methodology contained in the guidelines will also be used to validate predictions of coal performance made in EPRI studies on pilot-scale combustion testing (RP2425) and coal quality impact modeling (RP2256). These results will add to the data base on the impact of coal quality, improving the industry's understanding of the correlations of coal quality to such phenomena as slagging, fouling, erosion, and corrosion processes in power plant boilers and other systems. ■ *EPRI Contact: Arun Mehta (415) 855-2895*

## A Human Factors Primer for Nuclear Plants

Personnel who operate and maintain nuclear power plants play a crucial role in ensuring plant safety and reliability. Accordingly, the systematic application of human factors concepts to the design of plant systems and programs can pay off in improved plant safety and performance. A new report, *Human Factors Primer for Nuclear Utility Managers* (NP-5714), describes the field of human factors engineering and summarizes the opportunities for its application to nuclear plant operations, maintenance, and design.

The report is based on previous EPRI human factors studies (NP-309, NP-1567), as well as on extensive workshops and surveys through which human factors experts identified the needs of nuclear plant managers. Written in question-and-answer format, the primer begins with an overview of the field of human factors engineering, including its rationale, objectives, methods, and potential benefits. Subsequent chapters discuss the application of human factors engineering to nuclear power plants in such areas as work structure, personnel motivation and training, maintenance, and design of the human-machine interface in the control room and other plant locations. A final chapter presents information about human factors resources that are needed for various task assignments and how these resources may be obtained.



The primer emphasizes that human factors concerns must be addressed in a long-term, continuing effort and that effective application of human factors concepts requires analysis that goes beyond mere common sense. Available to member utilities since April, the primer has also been ordered in quantity by NRC, which plans to use it internally for training personnel. ■ *EPRI Contact: Howard Parris* (415) 855-2776

## Working With Regulators on DSM

Utilities are increasingly using demand-side management (DSM) programs to influence customer electricity use, producing customer savings on energy bills while simultaneously improving utility load factors. One important factor contributing to the success of DSM programs is regulatory acceptance and support. A new report, *DSM Regulatory Impacts* (P/EM-5631), presents survey results, a case study, and a resulting set of guidelines to help utilities improve regulatory relations pertaining to DSM.

On the basis of a survey of regulatory commissions in all 50 states, the report provides useful information on the current regulatory environment, the often differing perspectives of regulators and utilities, and trends in regulatory policies. In addition, it offers a detailed case study of the positive relationship between Florida Power and the Florida Public Service Commission. The report also includes suggestions for improving relationships with regulators, including the importance of emphasizing customer service as a corporate objective, the need to manage programs to reflect this corporate commitment, and the crucial role of a positive relationship based on open and frequent communication. ■ *EPRI Contact: William M. Smith (415) 855-2415*

CORRECTION: The April/May Tech Transfer News article on EPRI's *Coal Quality Information Book* (CS-5421) gave an incorrect telephone number for Project Manager Clark Harrison. For more information about the book and related EPRI research, Harrison can be reached at (412) 479-3503.

*Acid Deposition*

# Lake Acidification and Fish Mortality

*by Jack Mattice, Environment Division*

**ABSTRACT** *The effects of lake water acidification on fish populations are the concerns of wide-ranging studies on acid rain. Aluminum, calcium, and water pH interact in complex ways to produce toxicity effects in given fish species. A framework of computer models has been designed that works with water pH and concentrations of aluminum and calcium to produce an index of population maintenance. The index is then used to derive estimates of the probability that a given fish species will be found or can exist in a given body of water.*

Fish depletion is playing a role in the acid rain debate. In the early 1970s fish losses in Norwegian lakes were reported to be caused by acidification, and as a result, effects on fish became the initial focus of concern over sulfur and nitrogen oxide emissions, acid deposition, and surface water acidification. Concerns now have spread to include acidification effects on terrestrial ecosystems, human health, and man-made materials.

But fish have remained a focus of concern for three principal reasons.

- Aquatic acidification is still thought to be one of the major effects of acid deposition.
- Sport fishing is highly valued by a large segment of the public, and anything that affects it adversely becomes a national and international issue.
- From an ecologic standpoint, the status of fish is, to some extent, an indication of the effects of acidification on other animals and plants in their food chains.

Although it is important to be able to assess the damage to fish, it is just as important to be able to predict what will happen to fish populations in the future under different conditions of acid deposition, acidification, and mitigation. Only then can cost-effective strategies of environmental protection and power generation be adopted.

As part of the lake acidification and fisheries (LAF) project (RP2346), researchers have developed a modeling framework to assess effects of acidification on fish. The framework uses laboratory toxicity data on the effects of pH, aluminum (Al), and calcium (Ca) on fish survival, growth, and reproduction. These data are then used in a fish population model to calculate an index of the population's ability to maintain itself. By relating this index to the presence or absence of fish in acidified and unacidified lakes, predictions can be made about the occurrence of the fish either in a single lake or in multiple lakes in the same region.

## Toxicity studies

Four species are being studied in the LAF project: brook trout, rainbow trout, white sucker, and smallmouth bass. Only the work on brook trout is complete, however, and those results are discussed below.

Even though brook trout have been one of the most studied of fish with respect to the effects of acidification, the present study has accumulated more data on this species than have all other studies combined. In 17 experiments, more than 31,000 brook trout, including eggs, fry, juveniles, and adults, were tested. Experiments lasted from 10 to 193 days and involved as many as 84 different exposure combinations.

Responses of brook trout to pH, Al, and Ca and their interactions are complex. Ca at levels down to about 0.5 mg/L protects against the toxic effects of both pH and Al. In addition, at concentrations up to about 50–100 $\mu$g/L, Al can protect against toxic effects of low pH. For eggs, pH is a more potent toxicant than Al; conversely, for larval, juvenile, and adult fish, Al is a more potent toxicant than pH. Brook trout in their first year (eggs, larvae, juveniles) are more sensitive to acid conditions than are adults. Thus, what happens during these early life stages is probably most critical in affecting the occurrence of brook trout in an acidified lake. The complexity of these and other relationships requires that models be used to summarize the data in useful form.

Two questions of critical importance in the development of the LAF framework were addressed during in situ–laboratory comparisons: Do pH, Al, and Ca adequately describe toxicity under acidified conditions? Do laboratory toxicity tests accurately describe toxicity in lakes?

Regarding the first question, the answer, apparently, is yes. Dissolved organic carbon (DOC) and fluoride (F) do affect toxicity (they reduce it), but it does not seem necessary to consider them in defining toxicity. The effects of F were found only at concentrations higher than those in acidified lakes, and the effect of DOC, although it occurred at observed field levels, appeared principally to be one of reducing the inorganic fraction of Al. Temperatures at observed lake levels did not have much effect on responses of brook trout. Therefore, pH, Al, and Ca do appear adequate to define toxicity in acidified lakes.

The answer to the second question is that in situ–laboratory tests quite accurately represent lake toxicity. A model based on laboratory data was 82% accurate in predicting whether fish would live or die in the in situ tests. In contrast, a model based on the in situ data themselves was 91% accurate. Therefore, the use of laboratory toxicity data to predict actual lake conditions appears to be valid.

## LAF predictive framework

The LAF framework is flexible. It explicitly includes processes that can be quantified, but it only implicitly includes processes that cannot yet be estimated or measured (e.g., compensation or density-dependent population regulation). The latter responses can be added later when it is possible to do so objectively. The framework can deal with either increased or decreased acidity and with changes in stocking or fishing. The framework can include effects on mortality, growth, and reproduction at all stages of the life cycle.

The LAF framework consists of a series of three models that convert levels of pH, Al, and Ca in a lake or series of lakes into an estimate of the probability that the lake or lakes will contain fish. These models are the PHALCA, the FISHEGGS, and a regression model (Figure 1).

The PHALCA model is named for the toxicity matrix tested: different levels of pH, Al, and Ca. The model summarizes laboratory data in mathematical terms by using survival-time or response-surface analyses. Combinations of pH, Al, and Ca that have not been tested can be estimated by using the model. Model outputs are relative reductions in survival and fecundity (eggs per female).

Outputs from the PHALCA model are inputs for the FISHEGGS model. FISHEGGS is a standard age-structure population model. Baseline information in the model (such as age at mortality, proportion of fish that are female, age at maturity, eggs per female) were obtained from a fish population in an unacidified but soft-water (low-Ca) lake.

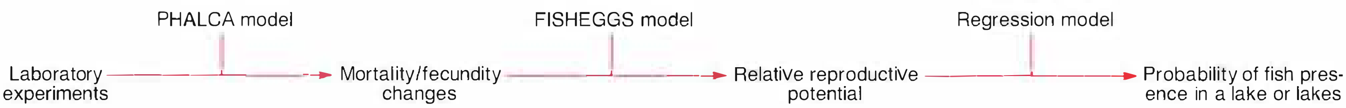



**Figure 1 Three models in the LAF framework. PHALCA estimates changes in mortality and/or fecundity from fish responses to pH, Al, and Ca in the laboratory. FISHEGGS uses these changes to calculate the relative reproductive potential, an index of a population's ability to sustain itself to the next generation. The regression model then calculates the probability that a fish population exists in a lake.**

This is important because fish in soft waters are less productive (grow slower, produce fewer eggs) than those in hard waters. The relative reductions in survival and fecundity derived from the PHALCA model then are used to modify the baseline (no acidification) rates for appropriate life stages.

The output from the FISHEGGS model is the value of a single index, the relative reproductive potential (RRP). This index can perhaps best be explained by defining reproductive potential and then showing how this is a relative value. Reproductive potential is defined as the mean number of first-generation yearling females produced per present-generation yearling female. For a population that is in equilibrium (i.e., one that just reproduces itself), the reproductive potential equals 1. If the reproductive potential is less than 1, the population will decrease, and if it is greater than 1, the population will increase. In other words, the more acid a lake is (i.e., below some threshold pH) the lower the reproductive potential will be. The RRP is the reproductive potential of a population in an acidified lake divided by the reproductive potential for the same population in a soft-water, but unacidified, lake.

Use of the RRP index has four advantages.

- It is a relative term that avoids the problems of dealing with actual numbers or densities of fish; such data rarely exist for acidified lakes.
- The effects of a wide range of acid conditions on different life stages and processes are integrated into a single estimator of the population's ability to regenerate itself.
- Such activities as stocking and fishing can be easily included.
- The single output makes calibration and evaluation of the model framework relatively simple.

The third model in the LAF framework is an empirical regression model. It relates the RRP index to the probability that a fish species will be present in a given lake. A logistic model is used because the dependent variable is binary: the fish are either present or absent. Development of this model requires data on water chemistry (pH, Al, Ca) and on the presence or absence of a fish species in a series of lakes that have historically supported the species. Historical presence is critical, of course, because some lakes cannot support certain species for reasons other than the chemical changes related to acidification (e.g., lack of spawning sites).

Water chemistry for each of the lakes in the data set is used to calculate the RRP index by using the PHALCA and FISHEGGS models. The probability of the occurrence of a fish population (presence = 1, absence = 0) is then regressed on the RRP for each of the lakes in the group. The above steps are used to calibrate this model. The LAF framework then can be used to predict the probability of the presence of a species in other lakes or in groups of lakes. However, it is important to check the accuracy of the predictions before using the framework to do so.

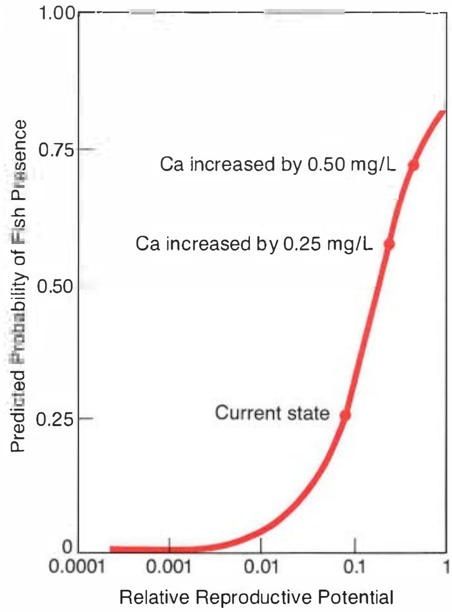
## Testing the framework

The best way to test a model is to evaluate the accuracy of its predictions by using a new set of lakes. This is not currently possible because of the lack of high-quality, comparable data sets. In fact, even the calibration data sets that do exist do not include measures of inorganic Al. As a result, this fraction had to be estimated from other water quality parameters. However, a less stringent test was made.

The existing data set was randomly sorted 20 times into two groups. For each sort, one group was used to calibrate the model and the other group to test it. In 18 of the 20 cases, the predicted numbers of lakes with brook trout were not statistically different from the observed number (95% confidence limits were roughly ±10%). Thus, the model does appear to provide reasonable predictions on the basis of this preliminary analysis. Further evaluation will be needed before the framework can be used with confidence.

The following example indicates the flexibility of the LAF framework. In this example, the LAF framework models are applied to a lake with pH = 5.2, inorganic Al = 110 $\mu$g/L, and Ca = 2.2 mg/L. These are the conditions in Salmon Pond, a lake in the Adirondacks. The LAF framework predicts that there is a 66% chance that the lake has a brook trout population. In fact, this lake does have a population of brook trout. Let us suppose that fishing is cut by 50% and that the yearling population of fish is increased 50% by stocking. The chance that the lake will support brook trout increases to 86%.

**Figure 2 When the Ca concentration in lake water is increased, the probability that fish can live there also increases.**




Perhaps it is easier to think of this in terms of a number of lakes with the same pH and concentration of Al and Ca. Under the base conditions, 66 of these lakes would most likely contain brook trout. With stocking and reduced fishing, the expected number would increase to 86, a 20% increase. This example shows that fishery management decisions can influence the abilities of fish populations to deal with acidification. Without the population part of the LAF framework (not part of purely empirical models), effects of stocking and/or fishing cannot be quantitatively included in predictions.

A second example illustrates the effects of liming (adding Ca) on fish presence (Figure 2). Take a second lake, with existing conditions of pH = 4.9, inorganic Al = 60

$\mu g/L$, and Ca = 1.4 mg/L. These are conditions similar to those that existed in Big Diamond Pond in the Adirondacks. This lake currently does not support a brook trout population even though the LAF framework predicts a 26% probability that the fish would be found there. Hypothetical increases in Ca of 0.25 and 0.5 mg/L result in increases in that probability to 63% and 80%, respectively. In other words, increases of about 18% and 36%, respectively, in Ca concentrations result in over two and over three times the number of lakes having similar conditions that will very likely have brook trout populations. Of course, this assumes that brook trout are able to immigrate into these lakes or are stocked. LAF analyses such as this one can be used, along with models developed in EPRI's LAMP project (RP2337), to schedule maintenance liming.

### Future efforts

The LAF framework needs further evaluation. Following validation, it can be used to evaluate mitigation or, coupled with the integrated lake watershed acidification studies (ILWAS) model (RP1109, RP2174), to predict brook trout responses to various acid deposition scenarios. In fact, the framework is currently being used by contractors to the U.S. Environmental Protection Agency as one way of calculating critical pH values for brook trout—the LAF framework will contribute to the National Acid Precipitation Assessment Program's 1990 final assessment.

EPRI's contractors (University of Wyoming; Western Aquatics, Inc.; Oak Ridge National Laboratory; McMaster University) are already working toward extending the LAF framework to the three other fish species (rainbow trout, white sucker, and smallmouth bass). In addition, they are searching for physiologic indicators of the relative sensitivity of species to acidification. If they are successful, it may be possible to extend application of the framework to other species without the need for accumulating such extensive toxicologic data.

*Photovoltaics*

# Amorphous Silicon Thin-Film Solar Cells

*by Terry Peterson, Advanced Power Systems Division*

**ABSTRACT** *Photovoltaic thin-film amorphous materials show much promise for making reliable low-cost, high-efficiency tandem solar cells for utility-scale power generation. EPRI is coordinating a multiuniversity research program for better fundamental understanding in these four areas: high-quality red-absorbing amorphous alloys, growth mechanisms of amorphous thin-film materials, amorphous thin-film device physics, and long-term device stability.*

Low cost and high efficiency are dichotomous goals that photovoltaic (PV) research must achieve if PV devices, or solar cells, are to play a significant role in utility-scale electric power generation. Thin-film solar cells look especially attractive for achieving the low-cost goal because they offer two important large-scale manufacturing benefits: First, they minimize material consumption—each device layer is made no thicker than nature requires. Second, their fabrication processes are well suited to automated large-area production.

In 1982 and 1983 EPRI conducted a wide-ranging review of PV state of the art (AP-3351). That review identified amorphous silicon, used in a novel tandem-cell configuration, as the leading thin-film candidate for electric utility applications. When used in tandem solar cells, amorphous silicon and its alloys are good prospects for meeting utility cost and performance targets for bulk power flat-plate modules, nominally $100/$m^2$ and 15% efficiency. An important factor in choosing to develop amorphous silicon PV technology instead of other promising thin-film materials is that there is keen worldwide interest in using amorphous silicon outside of PV applications. Therefore, PV amorphous materials research benefits synergistically from advances in related non-PV research. EPRI's research aims to advance thin-film solar-cell technology through university-based efforts to improve fundamental understanding of the materials.

Laboratory single-junction amorphous silicon PV devices are now nearing 13% efficiency, their practical achievable limit. Research on multijunction (two- and three-junction) solar cells, also called tandem cells, has produced small-area (1-$cm^2$) cells that are more than 13% efficient. The multijunction approach is attractive because it allows a single device to use different wavelengths of the solar spectrum separately, which makes it more efficient than a single-junction cell (Figure 1). The practical efficiency limit for amorphous thin-film multijunction devices is not yet well defined. But they appear capable of more than the 18% efficiency required to make power modules of 15% efficiency.

During the last dozen years, amorphous silicon research has given some understanding of the material itself and has led to substantial progress in thin-film PV devices. For continued progress, however, fundamental understanding of both materials and devices must improve.

To obtain a better understanding of amorphous materials, EPRI began a university research program about four years ago. An industrial advisory committee, composed of leading research scientists and engineers from the U.S. thin-film PV industry, helped both to formulate the program's objectives and to review the proposed university projects. The committee, together with key EPRI-sponsored university contractors, identified four areas in which better understanding is vital to the successful development of amorphous silicon thin-film devices.

- High-quality, red-absorbing amorphous silicon alloys
- Kinetics of amorphous thin-film deposition
- Physics of amorphous thin-film devices
- Long-term cell stability

The participants in EPRI's program have focused their research on these critical issues.

The present EPRI program consists of interacting, cooperative research projects at Princeton University, the University of Illinois, and The Pennsylvania State University. In addition, most of the original industry advisory committee members remain actively involved with the program and continue to provide feedback on the program's direction and emphasis. A key strength of the program is the high degree of interuniversity and industry-university interaction.

## Research results

EPRI researchers at Princeton University are primarily developing high-quality, red-absorbing amorphous silicon alloys (RP2824-2). To deposit thin films of these alloys, they are using dc- and rf-driven forms for a process known as plasma-enhanced chemical vapor deposition (PECVD), also called glow-discharge deposition. They are emphasizing careful materials preparation, using state-of-the-art high-vacuum equipment and techniques to reduce reactor contamination and maintain tight process control.

The Princeton group is investigating amorphous silicon-germanium alloys. Depending on their silicon-germanium ratio, these alloys can have optical-absorption edges ranging from that of amorphous silicon, about 1.8 electron-volts (eV), down to that of amorphous germanium, approximately 1.0 eV. Feed gas mixtures of $SiX_4$, $GeX_4$, and hydrogen are used to control the alloy composition (where $X$ can be fluorine, hydrogen, or both). The challenge is to lower the alloy's absorption edge, while maintaining the desirable electronic properties of amorphous silicon. So far, however, alloys with absorption edges below about 1.4 eV have always shown inferior properties. Nevertheless, the Princeton researchers have succeeded in depositing amorphous silicon-germanium alloys with absorption edges down to about 1.2 eV with properties that may be good enough for use in a tandem cell.

Amorphous thin-film deposition kinetics, the second recommended area for research attention, is an important issue because deposition machines will have to be designed and built to produce some 10 million $ft^2$ (1 $km^2$) of solar cells per year if thin-film PV is to be a real option for utility bulk power generation. This represents a significant step up from today's technology. To scale up to this level economically means increasing both the uniformity and growth rate of large-area film deposition. Important questions in this area concern feed gas decomposition kinetics and the effects of energetic particle bombardment on the growing film's electronic properties.

One way to study deposition and film-growth kinetics is to independently control the deposition parameters, including the quantity and energy of particle bombardment. This is the thrust of EPRI work at the University of Illinois, where researchers are

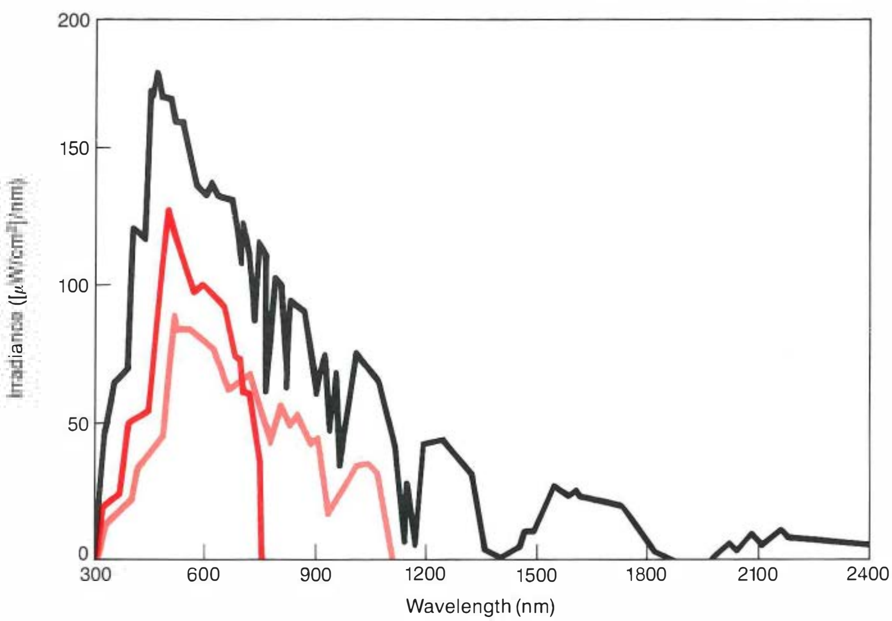
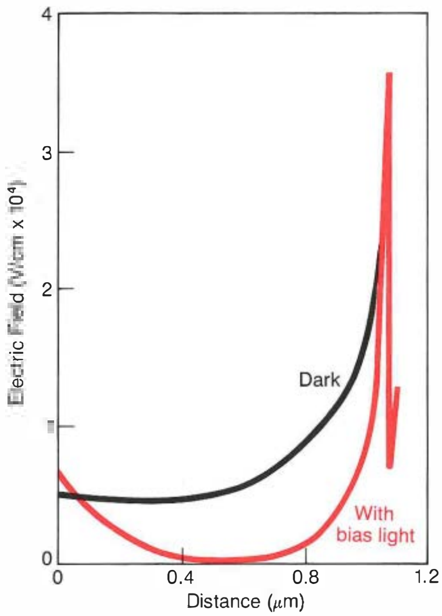



**Figure 1 Each layer in a multijunction PV cell is separately optimized to convert the energy in a portion of the solar spectrum, making the total cell efficiency higher than that of a single-junction cell. The black curve shows the sun's energy distribution. The color curves show how the energy would be absorbed by different layers in a multijunction cell.**

**Figure 2 The surface-photovoltage (SPV) measurement can be used to determine the average distance an electron diffuses in a semiconductor between photo excitation and decay to its equilibrium state. However, an accurate measurement requires that the semiconductor's internal electric field be negligible throughout the region in which the electron diffuses. This figure, generated with the Penn State device models, shows that the field in an amorphous silicon film is significant, even with strong bias illumination (which tends to neutralize the field). Therefore, the SPV method gives misleading results in this case.**




using reactive magnetron sputtering and remote-plasma PECVD to observe the film-growth process (RP2824-1).

Sputtering is a deposition technique that directly obtains the material to be deposited from a solid source. Atoms or molecules are knocked out of the source, or target, by a cascade of energetic ions. These ions come from a plasma discharge that is maintained in the deposition chamber by passing a current through a low-pressure inert gas, usually argon. When the particles ejected from the source hit and stick to the substrate they become part of the growing film. In *reactive* sputtering, a reactive gas (in this case, hydrogen) is injected into the deposition chamber along with the argon. Then, depending on the process conditions, a chemical reaction occurs at either the substrate or the target. In this way, a pure silicon target can produce hydrogenated amorphous silicon thin films. In *magnetron* sputtering, a magnetic field confines the plasma discharge near the target. This has two benefits—it greatly reduces potentially harmful substrate ion bombardment, and it lowers the required sputtering-gas pressure, which decreases film contamination. In the Illinois setup, the growing film may be optionally bombarded with energetic particles to study their effects independent of sputtering conditions.

To provide better insight into amorphous-material device physics, EPRI researchers at Pennsylvania State University are developing generalized numerical models to simulate device behavior by using a computer (RP2824-4, RP8001-3). The Penn State models are designed to be quite general and flexible, so they may be used to simulate a wide variety of electronic devices made of virtually any semiconductor—amorphous, single-crystal, or polycrystalline. Single- and multijunction PV devices are some specific simulations that these models can perform. These simulations provide correlations between PV device characteristics and measured material parameters. To date, they have been used to improve our understanding of several common materials-characterization laboratory experiments, including the surface-photovoltage measurement (Figure 2). These models are designed to serve as road maps to enable groups working on materials development to optimize their thin films for solar cells without actually making complete devices.

The fourth important research area, long-term device stability, is a concern that all three EPRI university projects are addressing. The fundamental issue here is the Staebler-Wronski (SW) effect, which is the name given to the amorphous silicon phenomenon of light-induced photoconductivity decrease. The SW effect causes a decrease in solar-cell efficiency over time. In present-day commercial modules this amounts to about a 15% degradation, relative to the initial efficiency, within the first year's use. Sophisticated device design promises to reduce this loss, but not without a cost in production yield. A more satisfactory solution awaits better understanding of the effect.

A new theory to explain the connection between the SW effect and the physics of amorphous silicon growth has recently come out of the Princeton work on silicon-germanium alloys. The Princeton theory proposes that the SW effect is a result of intrinsic defects in the material that are in thermal equilibrium at the usual growth temperature. These defects are then quenched into the material when it is cooled after growth. Princeton researchers are now testing this theory and seeking ways to minimize defect creation during film growth.

Another lead in the quest for a solution to the SW problem has come from some preliminary reactive-sputtering work at the University of Illinois. The EPRI researchers there find that the magnitude of the SW effect appears to decrease as the hydrogen content of the films decreases (Figure 3). This result is, as yet, tentative. Nevertheless, it under-

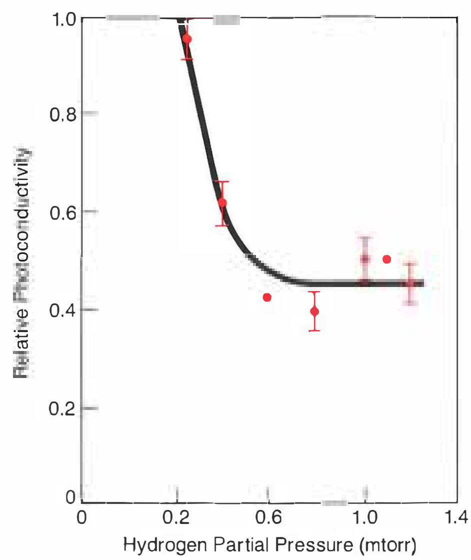



**Figure 3 The Staebler-Wronski effect can be seen in short-term laboratory experiments as well as long-term field tests. This figure shows the improvement in stability of reactively sputtered amorphous silicon, evidenced by the smaller relative photoconductivity decrease after a 30-minute light exposure, when its hydrogen content is reduced by lowering the sputtering-gas hydrogen concentration.**

scores the value of trying several grossly different film-growth techniques because the hydrogen-SW correlation has not been observed in "normal" PECVD-produced films.

To provide a focus for greater emphasis on the device-stability problem in the amorphous silicon research community, EPRI recently coordinated a voluntary, informal working group—the Stable Materials Advisory Research Task Force. This group of about a dozen researchers, representing most of the organizations now engaged in amorphous silicon research in the United States, will meet once or twice a year to discuss members' current understanding of the SW effect and possible new research directions from which to attack it.

EPRI has undertaken this long-term fundamental amorphous silicon research program because we are convinced that better understanding of the materials science underlying this technology is required if the PV industry is to supply U.S. utilities with efficient, long-lived amorphous thin-film solar cells. An important part of this program is to promote cooperation among interested university and industrial research groups to optimize use of available resources and minimize development time.

*Diagnostics and Troubleshooting*

# Expert System for Gas Turbines

*by Clark Dohner, Advanced Power Systems Division*

**ABSTRACT** *By sharing the knowledge of specialists on troubleshooting gas turbine problems in electric power plants, EPRI's gas turbine expert system (GTES) gives the apprentice access to much of the experienced technician's expertise. In an on-site demonstration, both experts and apprentices used GTES to isolate control system ground faults. On their own, the apprentices were unable to solve the test problems; with GTES, they solved the problems in about the same time as the experts.*

Troubleshooting gas turbine problems in electric power plants requires all the skills and knowledge of a seasoned technician. Unfortunately, there are too few of these experts to provide the assistance needed by apprentices in their efforts to analyze malfunctions and determine probable causes. But the expertise of the few can be made available to others by means of computer systems called knowledge-based, or expert, systems.

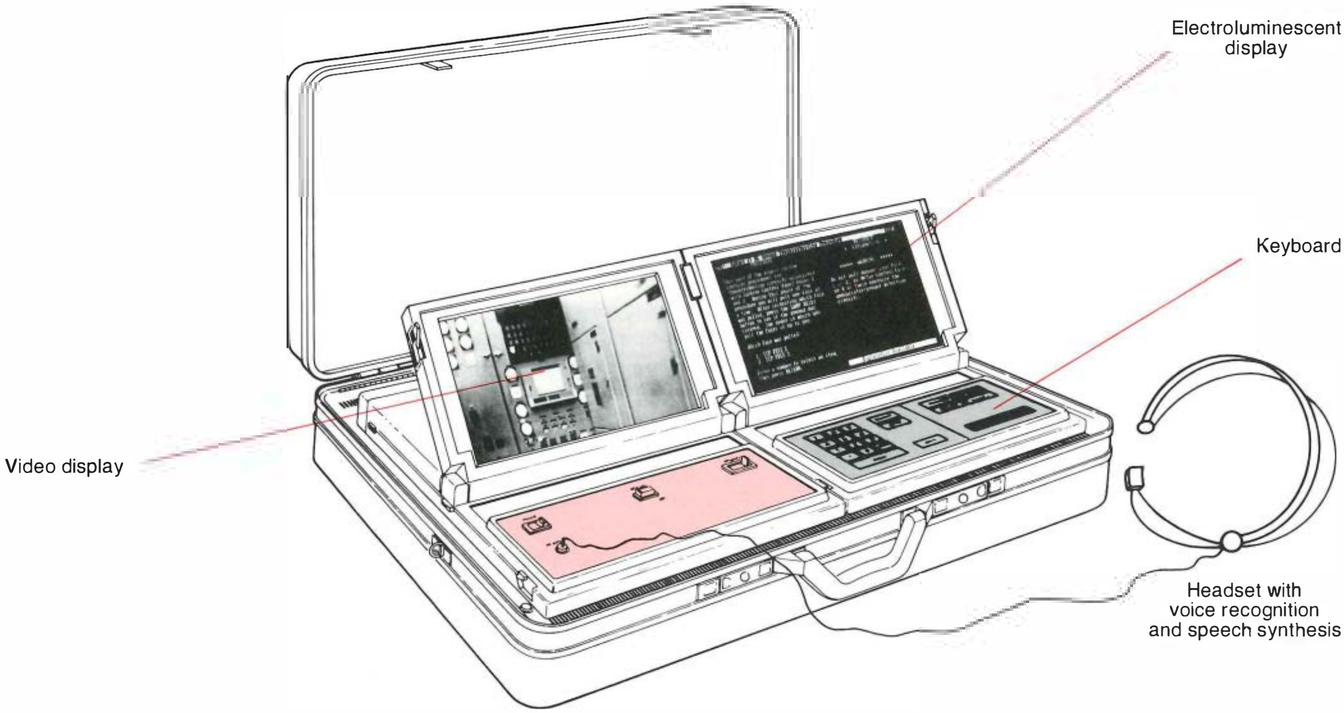
An expert system comprises a set of rules developed from the collective knowledge of recognized experts in a given subject area. EPRI sponsored the development of a prototype expert system designed to provide guidance to technicians conducting troubleshooting procedures in the power plant environment. This system, the gas turbine expert system (GTES), was tested at Jersey Central Power & Light's (JCP&L's) Gilbert station in Milford, New Jersey. The JCP&L plant is a combined-cycle facility comprising four gas turbines, four heat-recovery steam generators, and one steam turbine. The test at JCP&L is a milestone in the use of expert systems in electric power generating plants.

Because the GTES had to incorporate a number of capabilities, its development had to be the work of more than one contributor. Accordingly, JCP&L was the host utility and plant expert, General Electric provided the expertise on expert systems and gas turbines, Honeywell was the expert on user interface, and Arinc Research measured system effectiveness.

The expert system software was developed to reside in a personal computer (PC). It was developed by first obtaining information from the experts that could be written in the form of rules and then placed into an empty shell expert system. In this way changes and additions to the rules could be made without fundamental programming changes. (This is analogous to using a spreadsheet software program to develop a particular application spreadsheet.)

A key requirement was that the system be portable. Troubleshooting a gas turbine necessarily requires that the technician make checks at the component itself; therefore, the GTES user-interface unit is contained in an easily portable case. It can be carried to the gas turbine by the technician

Figure 1 After successful demonstration of the gas turbine expert system at JCP&L, the next-generation is being developed to assist operators in a wider range of tasks. The new system will be entirely self-contained. (The printer is not visible from this perspective.)




and plugged into a prewired data link that connects it to a PC-based system in the control building. This 30-lb (13.6-kg) user-interface unit contains a microcomputer, electroluminescent text/menu display, video display, special-function keyboard, 2-in 30-column printer, and voice recognition/synthesis system.

Troubleshooting rules from the expert system are supported by video pictures from a video disk system that uses one-time recordable disks. Graphic overlays to the video pictures are also allowed, which makes it possible for dimensions and labels to be applied and easily revised. The video disk allows the display of individual video frames (such as schematics), as well as motion sequences.

A useful field test of GTES required that the troubleshooting problems to be solved be pertinent to the host utility and the solutions be in sufficient depth to resolve the problems concerned. These requirements, coupled with time and funding constraints, meant that GTES would have to be rather narrow in domain but of sufficient depth to determine all probable causes of the particular conditions to be diagnosed.

The problem selected for troubleshooting was control system ground faults (including thermocouple grounds). These ground faults were one cause of gas turbine alarms and trips that occurred often enough at JCP&L to provide a practical check of GTES. Although this problem set is only one aspect of gas turbine troubleshooting, its complexity resulted in a rule-based logic system with a content equivalent to about 900 rules.

GTES installation and checkout were performed at JCP&L in 1987. Plant personnel were familiarized with the GTES equipment, and then two expert technicians and two apprentice technicians were trained for the test.

After training and further familiarization with the system, testing of simulated ground faults began. The tests consisted of two ground fault problems of comparable difficulty. Each of the four technicians attempted to solve the first problem by relying on his own troubleshooting skills and to solve the second problem by using GTES.

Neither of the apprentices (on his own) could solve the first problem, but both solved the second problem with the help of GTES. The experts solved both problems. Successful troubleshooting of these ground fault problems required about the same time, whether apprentice-solved with GTES or expert-solved with or without GTES.

As a result of the successful demonstration of the GTES, the next-generation expert troubleshooting system is being developed (Figure 1). It will expand the troubleshooting problem domain of GTES to include turbine startup and will consolidate all hardware and software (i.e., the remote workstation components used in the JCP&L test, as well as those located in the control building) into an easily portable unit. The expert information contained in the next-generation system will be pertinent to both combined-cycle plants and peaking-duty, simple-cycle units because the ability to start a gas turbine unit is important to both.

# Competitive Factors and Assessment Methods

by J. Sherman Feher, Planning and Evaluation Division

Utilities are experiencing growing competition with an increasingly uncertain future business environment. An important step in utility business planning is to assess the degree of competition from independent power producers, possible electricity generation by commercial and industrial customers, substitutes for electricity, and other sources of competition. The primary goal of a project recently initiated by EPRI is to provide utility management and planners with a variety of business planning methods and information to better assess this environment (RP2937). The research has several tasks.

- Provide an understanding of electric utility competitive factors
- Convey insights learned from other industries that have been deregulated
- Review methods used by utilities as well as other industries to assess competition
- Conduct a few utility case studies with the most promising assessment methods

## A framework for understanding competition

Three perspectives affect a firm's business and economic outcomes when dealing with its customers in a competitive environment—political, managerial, and technological. In a competitive environment, the political perspective expands from regulators to include legislators, special interest groups, and the general public. The managerial perspective involves operating issues, such as resource and capital allocation, personnel, and information systems. The technological perspective deals with the timing, scale, and configuration of productive facilities.

In addition to a wider scope associated with each perspective, the various organizational levels have to be familiar with all three perspectives to ensure an integrated view of competition. Using this framework, EPRI contractor Putnam, Hayes, and Bartlett, Inc. (PHB) developed a conceptual model for assessing competition, which has as its focal point the market or utility customers (Figure 1).

## Insights from other industries

Researchers examined other industries that had undergone economic deregulation. Although the insights gained from this work cannot be used to predict what will happen in the electric utility business, they can help utility personnel understand the emergence of competition in this industry. One important insight is that competition generally causes both substantive and process effects for an industry.

Substantive effects include market effects on prices and costs and the subsequent reactions from customers, suppliers, politicians, and others. Process effects include changes in existing commercial, managerial, and political relationships, such as the way employees respond to a changing business environment, the way customers view an unregulated enterprise, and the way politicians respond to a change that lessens regulation. Obviously, these effects interact; however, one must be aware that the effects fall into two separate categories. Exclusive attention to substantive effects can prove costly to a utility that discovers too late that the norms of industry behavior change with competition.

The first and perhaps most important substantive effect is that the terms of suc-

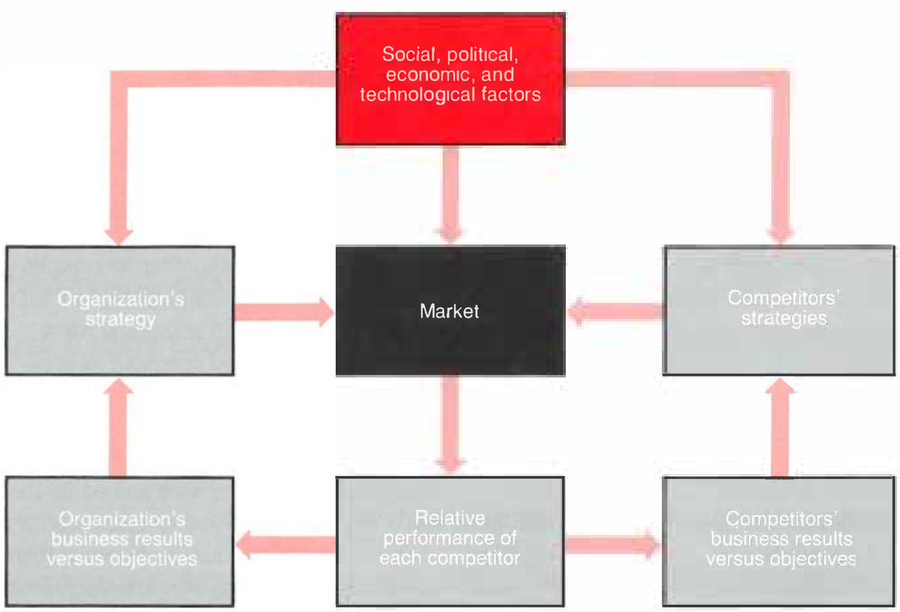



**Figure 1** This conceptual competitive assessment model demonstrates that the market is continuously changing as a result of many factors. Social, political, economic, and technological permutations affect not only the market but also the strategy of the organization and its competitors. As the market responds to the relative performance of each competitor, that response also alters strategy decisions.

**ABSTRACT** *As utilities experience increasing competition, managers need a better understanding of the changing business environment and the methods to assess that environment. EPRI-sponsored research examines the emergence of competition and its implications for business decisions. Researchers examined other industries that have become more competitive and have undergone economic deregulation. They then reviewed a number of methods for assessing competition common to other settings to determine their usefulness in utility applications.*

cessful competition change with deregulation. As noncore customers threaten to leave the system to lower their cost of electric service, a utility may lower its rates. If the utility reduces rates to these customers, they become much less profitable to the utility. On the other hand, core customers, who are often a low-profit source because of regulation-based price breaks, may become a source of greater profit after regulatory change. An example is the airline industry. Before deregulation, long-haul routes were the most profitable; short-haul flights were the least. Deregulation reversed that phenomenon. Competition on long-haul routes became more intense, but the existence of fewer competitors on short-haul routes made the previously unattractive routes appealing to some airlines.

In a less-regulated environment where prices are set by market forces, capital gains and losses take on new significance. While regulated, a firm has little opportunity to capture capital gains because prices are set on the basis of average historical costs. In contrast, competitive firms must explicitly consider their potential to create capital gains by their own actions and to incur capital losses as a result of the actions of others.

In a less-regulated environment, politics tends to become more important, as well as to evolve into a different form. In contrast to the commonly held belief that less regulation means less political maneuvering, in reality politics becomes more significant but in a different way. For example, if as postulated earlier, core customers become more-important sources of revenue, this group of customers will wield greater political force in a competitive market through a variety of new mechanisms. At the same time, the regulatory instrument historically used to protect the interests of this group will have weakened.

Competition tends to feed on itself. In most deregulated industries, the introduction of a small amount of competition has generally led to a cascade of competitive initiatives. The natural gas industry is going through this experience, as wellhead price decontrol has led to decontrol initiatives throughout the pipeline and distribution system.

Competition also produces a number of process effects. Corporate culture changes in a more competitive environment. When corporate practices change, so do managerial and cultural values. This change must permeate the whole organization. For ex-

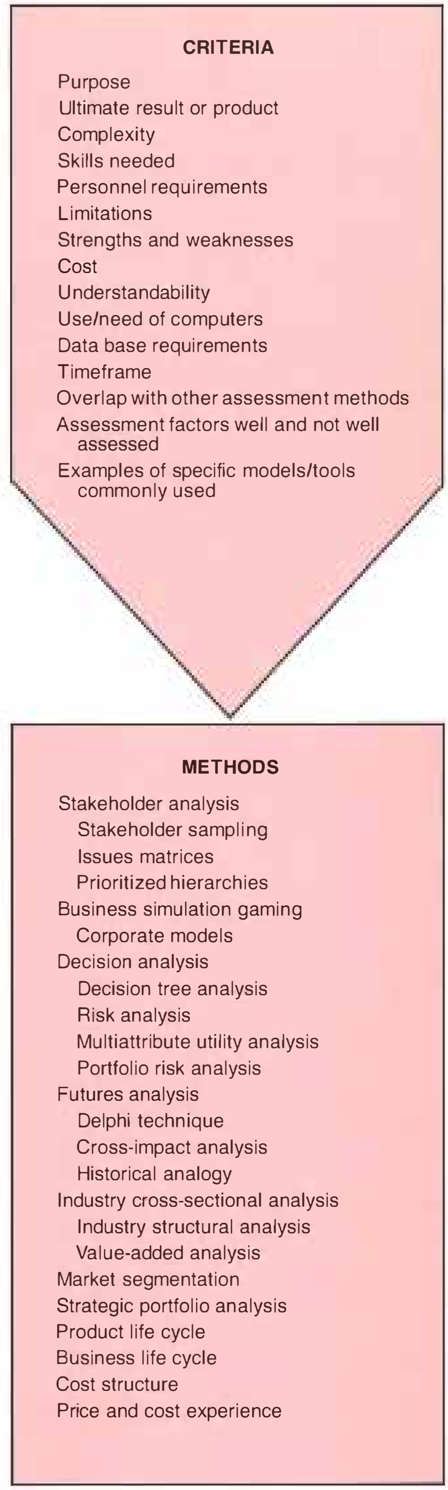



**Figure 2** **After determining the competitive assessment methods that may be appropriate for various utility situations, PHB formulated a set of criteria against which these methods can be evaluated.**

ample, successful managers use analysis in making decisions, but they also use pattern recognition—relating a managerial challenge to past patterns they have experienced. In a changing business environment, managers must develop new patterns to guide their decisions.

All change is a strategic challenge. Changes emphasize the importance of strategy, but during periods of rapid change, managers will lack the time to address strategic issues. Strategic thinking deals with this challenge by striving to place day-to-day decisions in a broader context, in contrast to conventional strategic planning, which relies primarily on analyses and planning documents.

### The roles of technology

Historically, technology has played a significant role for electric utilities. From the 1930s through the early 1970s technology was the primary contributor to the declining cost of electricity. However, decreasing demand and the ability to take advantage of scale economies is changing the role of technology. How technology is selected and managed will play a major role in determining the winners and losers of the future. In a more competitive situation, utilities that focus on customers' needs and differentiate their products accordingly can be more profitable. Technology plays an important role in product differentiation by lowering costs and having the customer benefit from service-related attributes of electricity. A future utility's technology strategy must recognize the following.

- A technology's cost, performance, and timing relative to the competition
- The technological, managerial, and political business risks
- The technology's operational and functional roles
- The strategic goal for using the technology

### Competitive methods

A number of mini case studies have been done that show how utilities are currently using competitive assessment methods for different situations. PHB evaluated a number of methods for assessing competition, using a number of criteria (Figure 2). In addition to evaluating competitive assessment methods, PHB is developing and testing a competitive screening and strategy tool for utilities. One important realization that came from this study is the need for a generalized approach that matches different assessment methods to the needs of a given competitive situation.

The study will soon be completed, and the final report is expected to be published soon. A number of case studies are planned to be conducted in 1988 and 1989. These case studies will apply competitive assessment methods not generally used by electric utilities, as well as the newly developed EPRI–PHB competitive screening method, to various competitive environments.

A national conference will be held on December 13 and 14, 1988, in Washington, D.C., to report on the results obtained thus far in this project.

*Environmental Risk Assessment*

# Effects of Electric Fields on Animal Fetuses

*by Robert Black, Environment Division*

Researchers at Battelle, Pacific Northwest Division, have completed an experiment to examine the effect of exposure to strong electric fields on the frequency of congenital defects observed in the offspring of female rats exposed throughout their lives to electric fields. The experiment is the culmination of nearly 10 years of EPRI-sponsored studies of the effects of strong electric fields on the progeny of swine and rats. The original study, begun in 1978, compared two groups of Hanford miniature swine, one of which was exposed to a 65-kV/m electric field for 20 hours per day. This level was chosen to simulate exposure to a human standing directly under a 765-kV transmission line. The study's objectives were quite broad. In addition to reproductive performance and occurrence of malformations, the researchers studied effects on behavior, blood chemistry, nervous system function, growth rate, and development (EA-4318).

A possible effect on the occurrence of malformations in the exposed group was found during the first phase of the experiment, but a second breeding of the exposed animals failed to produce an effect on the proportion of litters with malformed fetuses. Except for some small differences in behavior between the exposed and unexposed offspring, no other biologically significant results were found.

Interpretation of the findings was difficult because of the relatively small numbers of litters studied and the occurrence of an epidemic of swine dysentery during the experiment. There was also some uncertainty about the background rates of malformations. In addition, there was no consistent pattern of malformations such as are seen following exposure to a true carcinogen. Nevertheless, it was decided to pursue the issue of the potential teratogenicity (*terato:* the ability of an agent—chemical, physical, or biologic—to cause serious deviation from normal development) of strong electric fields in another species—the rat.

Two follow-on replicate studies with rats employed a protocol similar to that of the swine study. Two successive studies were

**ABSTRACT** *A possible relationship between exposure to high-intensity electric fields and birth defects has been conjectured for many years, but the results of studies undertaken to settle the matter have been ambiguous. The results of a recently completed, more-rigorous study, however, have resolved the matter. Rats exposed to a range of electric field intensities produced no more offspring with birth defects than did unexposed controls.*

conducted because the number of animals that could be exposed at one time in the existing facility was limited. There was an apparent effect of exposure on the proportion of litters with malformed fetuses in the first experiment but not in the second. An outside team of teratologists concluded that the defects seen in the exposed litters were not consistent with a true effect. Once again, chance variation attributable to limited numbers of experimental animals could not be excluded as the cause of the apparent effect.

Despite the lack of an unequivocal effect, EPRI decided to pursue the issue vigorously because of its obvious importance to the electric utility industry. To conduct the next experiment, a new, larger, and more sophisticated animal exposure facility was designed. A number of safeguards were built into the system to minimize the possibility of spurious effects attributable to the exposure apparatus itself.

The design of the facility allows simultaneous exposures of up to four different groups of animals in the same room. Each group can be exposed to a different field intensity, and each unit is shielded from stray fields or electrical effects from the adjacent modules. Exposure and environmental conditions in the exposure facility, including field strength, corona, temperature, and humidity, are monitored and controlled by a dedicated minicomputer.

In addition, the experimental design called for a number of steps to eliminate either experimental biases or the effects of extraneous variables and to ensure that any effects observed would be the result of electric field strength, the primary experimental variable. Each of the four subject groups was designated by a color code, corresponding to one of the four experimental exposures: 0 kV/m (control), 10 kV/m, 65 kV/m, or 130 kV/m. Only the project engineer responsible for overseeing and monitoring the exposure conditions knew which color corresponded to which field strengths. Experimenters and animal handlers were both kept "blind" to the exposure status of the animals, and the code was not broken until the teratologic data had been analyzed at the end of the study.

The four electric field strength exposure levels used in the study was the result of several lines of argument and would test the hypothesis that potential biologic effects vary linearly with field intensity; in other words, the possibility of a dose-response relationship would be tested. It was also desirable that the maximum study exposure level exceed the maximum possible level to which humans can be exposed in normal environments. The selection of the 130-kV/m field involved special considerations, including scaling between rats and humans. Because of their size and shape, rats must be exposed to proportionately higher fields in order to approximate a comparable exposure in man. Thus the lowest exposure level, 10 kV/m, approximates the field intensity to which a human would be exposed at the edge of the right-of-way of a 500-kV line. The highest study field level, 130 kV/m, approximates a human exposure of 30 kV/m, which is about three times higher than the most intense electric field beneath the centerline of a 765-kV line.

To minimize any effect attributable to the position of the exposure unit in the room, the groups and their corresponding high-voltage power supplies were rotated among the four exposure units each week.

Two generations of animals, designated F0 and F1, were used in the study. Female rats of uniform age were acclimated to the Battelle facility and then mated to male rats. When tests showed that mating had occurred, each female was randomly assigned to one of four exposure groups: 10 kV/m, 65 kV/m, 130 kV/m, and the control group, 0 kV/m. Sixty-eight females were assigned to each group.

Each group was exposed to electric fields under carefully controlled conditions for 19 hours per day through gestation (21 days) and birth of the pups. After weaning, the F0 dams and all but two female pups from each litter were removed from the experiment. On reaching reproductive age, second-generation animals (F1) were mated to unexposed males. At the end of gestation, the females were sacrificed, and the unborn litters were carefully examined for birth defects.

The proportion of litters in which the fetuses exhibited abnormalities was very

**Table 1**
**MALFORMATIONS IN RATS EXPOSED TO ELECTRIC FIELDS FROM CONCEPTION TO END OF GESTATION**

| | Field Strength (kV/m) | | | |
|---|---|---|---|---|
| | 0 | 10 | 65 | 130 |
| Number of litters | 99 | 83 | 92 | 101 |
| Litters with malformed fetuses | 5 | 3 | 9 | 5 |
| Litters affected (%) | 5.1 | 3.6 | 9.8 | 5.0 |

close to the 5.0% rate of the control group (Table 1): 3.6% in the 10-kV/m group; 9.8% in the 65-kV/m group; and 5.0% in the 130-kV/m group. The differences between these groups are not statistically significant.

These results, obtained by using a large number of animals, suggest that exposure to strong electric fields does not produce birth defects in animals. Although extrapolation of the results of animal studies to humans is always somewhat uncertain, it does not appear that electric fields (even if they are experienced 19 hours a day and are three times more intense than those directly beneath high-voltage transmission lines) can be linked to birth defects and developmental malformations in humans.

This recently completed study provides the strongest evidence to date in support of such conclusions. A standing advisory committee to EPRI, consisting of distinguished scientists who are knowledgeable of the biologic effects of electric and magnetic fields, reviewed this study. The committee members approved the design, quality, and statistical power of the study, and they concurred in the study's conclusion that no association between electric field exposure and teratologic effects was indicated. The committee also suggested that further EPRI studies of the effects of electric fields on fetuses would be unnecessary.

Consequently, future research will be directed to the study of the possible teratologic effects of magnetic fields. There are scattered reports in the scientific literature of positive teratologic effects of magnetic fields in several different animals, but most of those studies involved small numbers of animals, and in some cases, the studies could not be replicated. Nevertheless, because relatively little work has been done on magnetic field effects and of the possibility that magnetic fields may be associated with the incidence of cancer in humans, a new and carefully designed animal study is being initiated. A study design similar to that of the electric field study will be used.

*Coal Plant By-products*

# Advanced $SO_2$ Waste Management

*by Dean Golden, Coal Combustion Systems Division*

**ABSTRACT** *The costs of managing waste produced by emissions control equipment are important factors in evaluating control systems. Comprehensive EPRI studies have characterized waste products; developed designs for waste handling, disposal, and utilization; and estimated waste management costs for five $SO_2$ control technologies.*

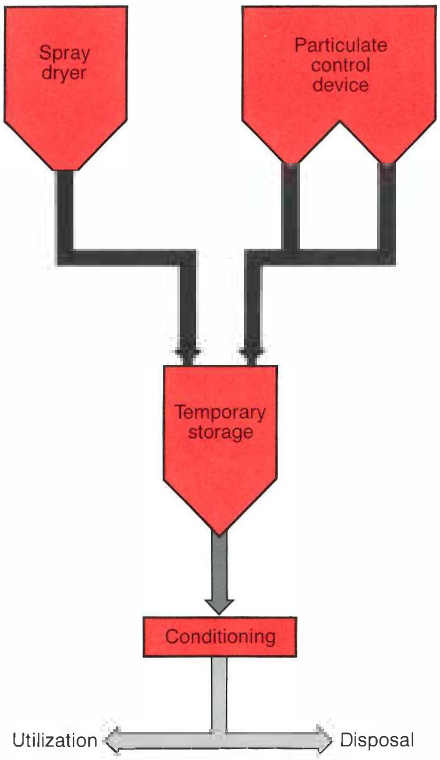
Capital and operating costs associated with managing wastes produced by $SO_2$ emissions control equipment are important factors in evaluating and comparing alternative $SO_2$ control systems. Over the past eight years, EPRI has conducted a number of studies to provide utilities with cost information on waste management for conventional wet scrubbing. More recently, EPRI sponsored a comprehensive investigation to assess waste management costs and issues for five alternative sulfur-reduction technologies: spray drying, atmospheric fluidized-bed combustion (AFBC), limestone furnace injection, dry-sodium injection, and advanced coal cleaning. For each technology, studies have characterized waste products; developed engineering designs for effective waste handling, disposal, and/or utilization; and estimated waste management costs.

The first study, completed in late 1986, evaluated spray dryer wastes. Results showed that these wastes can be managed without excessive operating and economic problems for utilities or adverse environmental effects. However, on a dollar-per-ton-disposed basis, spray dryer waste management costs were found to be higher than those for either conventional fly ash or scrubber sludge alone. This finding indicates that cost estimates for new and retrofit spray dryer applications must be revised upward from those produced earlier by EPRI, under which waste management costs from all sulfur-reduction processes were assumed to be equal. Similar studies for AFBC, limestone furnace injection, and sodium injection were completed in early 1988 and are in draft report form.

Figure 1 is a schematic of a typical spray dryer waste management system. The process involves five basic activities.

- Transfer of waste material from the spray dryer and particulate control device to a temporary storage facility
- Storage
- Conditioning to improve the material's

**Figure 1 Typical spray dryer waste management system, showing the transfer of waste material to the temporary storage facility, conditioning to improve the waste's handling characteristics, and transportation to site for either utilization or disposal.**




handling characteristics (e.g., adding water to reduce fugitive dust emissions)

- Transportation to a disposal site or to a location where the material is used
- For waste material not used, placement and containment at a disposal area

Results of this investigation are presented in *Calcium Spray Dryer Waste Management: Design Guidelines* (CS-5312) and in *Utilization Potential of Advanced $SO_2$ Control By-products* (CS-5269), which is currently available as an interim report. (A final version of CS-5269 will be published in mid 1988 at the conclusion of work on all five technologies.)

The spray dryer waste management study was conducted in four steps: characterizing spray dryer waste, surveying existing and planned spray dryer installations, developing conceptual designs and case studies for new and retrofit spray dryer installation, and evaluating the utilization potential of spray dryer waste.

## Waste characterization

Investigators analyzed waste material from seven utility spray dryer installations to measure physical, chemical, and leachate properties important in the design of a waste management system. Results show that although properties of spray dryer waste are generally similar to those of conventional fly ash, spray dryer waste is finer and more caustic, has a higher heat of hydration, and produces a more alkaline leachate. It can also become tacky when wet and exhibits self-hardening properties similar to cement. Flowability test results indicate that normal, relatively dry spray dryer waste is generally free to average flowing. With higher moisture content, however, the material may set and create serious storage problems. Flowability testing also indicates that spray dryer waste aerates easily and once aerated, it retains air. Such characteristics are advantageous if controlled fluidized handling is used. But flowability also indicates a potential for flooding, flushing, and flow rate limitation problems. (Flooding and flushing refer to conditions in which an aerated bulk solid behaves like a fluid and flows uncontrollably through an outlet or feed mechanism.) Sampling and analytic protocols are documented in CS-5625; characterization results are detailed in CS-5782.

## Survey of waste management systems

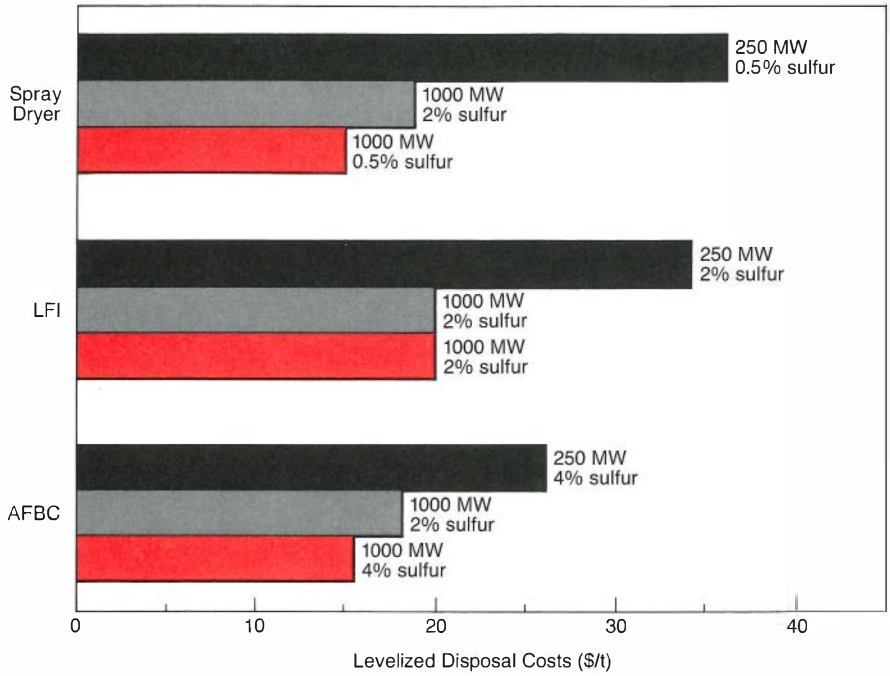
Researchers collected data from 18 existing and planned spray dryer waste management systems. Results indicate that waste management methods and equipment for these systems are similar to those used for conventional fly ash. Separate conveyors are typically used to transfer wastes from the spray dryer and particulate control device to a temporary storage silo. To transfer waste from the particulate collector, dilute-phase pressure pneumatic systems are most common, although pneumatic vacuum systems and mechanical systems are also being used successfully. Mechanical conveyors (primarily drag chain, bucket, or screw-type) were installed initially in the existing facilities surveyed to transfer waste from the spray dryer. However, all but five of these conveyors were converted to pressure or pneumatic vacuum systems because of excessive wear and parts abrasion. Most facilities that use dry disposal methods condition the wastes with a small amount of water before transporting the wastes by truck to an unlined landfill.

## Conceptual designs and case studies

On the basis of the results of waste characterization and survey and using EPRI's *Technical Assessment Guide,* researchers developed spray dryer waste management conceptual designs and designed new and retrofit spray dryer waste management systems for a hypothetical pulverized-coal-fired power plant burning low-ash western subbituminous coal. For both the new and retrofit designs, collected waste was transferred to a common surge silo (the waste material collected at the bottom of the spray dryer by a mechanical conveyor, and particulate collector waste by a pneumatic system). From there it was taken to either a slurry preparation area for recycle or to a disposal silo through a dilute-phase pressure pneumatic conveyance system. Waste withdrawn from the disposal silo was assumed to be conditioned with water and transported by truck to landfill. Similar conceptual designs and case studies have been completed for AFBC, limestone, and sodium furnace injection technologies for publication this year.

For both the new and retrofit spray dryer cases, the power plant was assumed to be a two-unit 1000-MW station. The new facility was assumed to be equipped with a fabric filter, whereas the existing station was assumed to be using an electrostatic precipitator at the time of the retrofit. Estimated total annual levelized costs for the spray dryer waste management systems up to and including placement in an unlined landfill were $3,029,000 (0.53 mills/kWh, or $14.69/t) for the new plant and $2,760,500

**Figure 2 Comparison of levelized disposal costs by technology. The common basis for comparison is shown in gray. The LFI process removes 50% of the sulfur, whereas AFBC removes 90% and the spray dryer, 70%.**




(0.63 mills/kWh, or $17.40/t) for retrofit installation. Figure 2 compares these waste management costs for spray dryer, AFBC, and limestone furnace injection technologies with new unit levelized costs for managing fly ash and scrubber sludge.

### Utilization

Current fly ash utilization options were evaluated and ranked in terms of technical feasibility and marketability on the basis of the physical properties, handling characteristics, chemical composition, environmental effects, and processing requirements of spray dryer waste. In this analysis, the utilization potential for spray dryer wastes was found to be similar to that for type C self-hardening ashes commonly found at plants in western and midwestern United States. Of the options considered, seven applications—structural fill, cement replacement, stabilized road base, synthetic aggregate, lightweight aggregate, mineral wool, and brick production—were most attractive.

*Plant Operations Limits*

# Improving Nuclear Plant Technical Specifications

*by John Gaertner, Nuclear Power Division*

Technical specifications are the NRC-approved requirements that control the normal operating limits for nuclear plants. Typically containing thousands of separate specifications and consisting of hundreds of pages, they govern many day-to-day decisions of the plant operating staff. Technical specifications contain such items as surveillance test intervals (STI), allowed out-of-service time (AOT) for failed components, instrument set points to trip the reactor, and the minimum equipment required under all operating modes. Continuous compliance with all specifications is mandated by NRC.

The original intent of technical specifications was to ensure that plants were run in accordance with the conditions described in the safety analyses for plant licensing. Over the years, such specifications have become complex, contributing to plant unavailability and causing other operational problems. Meanwhile, the safety-related basis for the requirements is often not evident.

Utilities and NRC generally agree that changes in technical specifications for nuclear plants are desirable. The industry and NRC are coordinating their activities to facilitate changes. In 1985 a utility industry Technical Specification Improvement Committee and the NRC Technical Specification Improvement Program each produced reports that agreed in many respects on the need for and a process to achieve broad-scale specification reform. Nuclear reactor owners groups have made significant progress in carrying out these recommendations; NRC has issued a policy statement for facilitating specification improvement, and both the industry and NRC are carrying out the recommendations of the policy statement.

### EPRI program

Meanwhile, EPRI has recognized that methods developed for doing probabilistic risk assessment (PRA) could be used to calculate the effects of specific proposed changes on plant safety. Having a sound technical basis, utilities would be able to justify requests to NRC for technical specifications optimization.

PRA methods can identify the sequences of events or combinations of failures that cause undesirable consequences, such as (1) failure of a safety system, (2) failure to perform a safety-related function, (3) reactor core damage, or (4) radionuclide releases from the plant. The methods also estimate probabilities for even the most unlikely of these scenarios. The detailed plant models, usually fault trees, and their solution sets, called cutsets, can be modified to consider the effect of technical specification requirements on these undesirable end-state probabilities.

EPRI has sponsored development of a theory and a computer code, SOCRATES, to facilitate these risk-based specification evaluations. These developments are described in NP-4317, and the PC version of the SOCRATES code is available from the Electric Power Software Center for utility use. An overall methodology for analyzing technical specifications was also developed under EPRI sponsorship. Two significant applications of the methodology were then completed on actual nuclear plant problems.

**ABSTRACT** *Technical specifications are the NRC-approved requirements that limit the day-to-day operations of nuclear power plants. The industry and regulators agree that specification changes, which improve plant operations without significantly affecting safety, are desirable. EPRI has developed a methodology and a computer code that use risk-based analysis methods to justify specification changes. EPRI sponsored demonstrations of the code and method at two nuclear plants. The results provide a technical justification for relaxing testing requirements, component out-of-service times, and reactor set points. The method is expected to have broad utility applicability.*

## Application at LaSalle

The first study, cosponsored by Commonwealth Edison, used the risk-based method to justify changing three problem technical specifications at the LaSalle station (NP-5238). The utility has plans to use these study results to obtain NRC approval for the proposed changes and is also now using the same methodology to study other specification problems.

In preparation for this study, an experienced operations engineer and licensed operator reviewed the entire set of technical specifications for LaSalle Unit 2. The purpose of the review was to identify, classify, and precisely define all known specification problems. The scheme that was used in the review classified all problems according to cause and effect (NP-5475).

From this data base, the operations staff at LaSalle selected three technical specifications that posed documented operational or economic burdens. In addition, each had been targeted by the staff for near-term resolution. For each problem, they proposed alternative strategies with the potential for equal or greater safety benefits. Researchers then developed a process for evaluating strategies, which compared the incremental risk of using each proposed alternative with the base case risk of using the existing technical specification unchanged. The process is structured so that incrementally more-detailed calculations are performed until the risk impact is shown. This stepwise approach ensures that the analysis effort is optimized.

For each of the three problem specifications, the analysis indicated that at least one of the proposed alternative strategies would be easier to perform and yet have no adverse effect on safety. The analyses produced a technically sound basis for the proposed changes. Moreover, the analytic method proved robust in its application to the three diverse problems of diesel testing, reactor scram set points, and AOTs for valves in a reactor scram system. The study used the SOCRATES code, which efficiently shows the changes in system unavailability or risk that result from changes in AOTs or STIs. The SOCRATES code proved useful in two of the three case studies.

The analytic results would justify (1) much less diesel testing, (2) fewer reactor scrams, and (3) a more practical AOT, as well as an improved testing program for the scram discharge volume system. In one analysis, probabilistic techniques made possible the identification of a component failure mode that had not been detected by current surveillance.

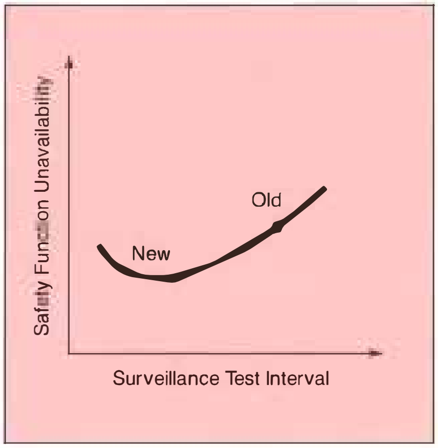
This study conclusively demonstrated that risk-based evaluations can play an important role in the improvement of nuclear plant technical specifications.

## Application at Hatch-2

The second study, cosponsored by Georgia Power, applied the risk-based methodology for optimizing groups of STIs and AOTs in multiple systems. The process allows a utility to conduct trade-offs between one specification change, which when considered singly could decrease safety, and another specification change, which alone would improve safety. Together, cost-effective improvements can be made without reducing the overall plant safety level.

**Figure 1 In the case where a longer AOT is desired to improve maintenance, analysis A shows that such an AOT change alone might decrease safety, but analysis B shows that adopting a shorter STI would increase safety. Therefore, the net effect of both changes is better maintenance with no decrease in safety.**


Analysis A




Analysis B

The methodology was successfully demonstrated in a case study of the emergency care cooling system (ECCS) and containment heat removal function STIs and AOTs for the Hatch-2 plant. Hatch-2 plant models were developed to identify and evaluate trade-offs. Projected costs or cost savings associated with each proposed specification change were also developed and integrated into an optimization model. From the many combinations possible, the process led to the identification of a proposed set of optimal STIs and AOTs for those Hatch-2 systems. The proposed set of STI and AOT changes can be characterized as follows.

- Three STIs were to be tightened from three months to two months, while 24 STIs and AOTs were to be extended.
- Operating costs would be reduced by doing fewer tests, thus avoiding unnecessary plant shutdowns, improving repair of failed equipment, causing less wear on equipment, and reducing diversion of plant personnel.
- Plant safety would be unchanged by ensuring that the combined effects of the final proposed STI and AOT changes do not decrease safety (Figure 1).

Because Hatch-2 is a representative BWR plant, application of the same methodology to other BWR plants can be expected to lead to the same type of STI and AOT improvements. The methodology can also be applied to the analysis of other reactor functions (e.g., containment isolation) and to evaluations for temporary technical specification relief on short notice. In the latter evaluations, other trade-offs (e.g., additional testing during the extended AOT) may be made to justify continued plant operation. The study will be reported in an EPRI report on reliability- and risk-based technical specification improvements to the ECCS and the containment heat removal system at Hatch.

This demonstrated risk-based analysis method is now ready for wide utility application, and it should play a significant role in the implementation of new technical specifications that will result from the industry and NRC reform efforts now under way.

## Achievement

The methodology can be used for optimizing individual technical specifications and for considering multiple specifications on a single system or multiple specifications on multiple systems. The process has proved useful for optimizing STIs and AOTs and for evaluating the need for trip set points. In addition, the method is applicable to evaluation of permanent changes in technical specifications, or it can be used for temporary relief from a specification requirement that might otherwise require a shutdown.

# 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

**Proceedings: 12th Annual EPRI Contractors' Conference on Fuel Science and Conversion**
AP-5460-SR Proceedings; $55
EPRI Project Manager: H. Lebowitz

**Development of Beta Batteries for Utility Application**
AP-5575 Final Report (RP128-7); $40
Contractor: General Electric Co.
EPRI Project Manager: R. Weaver

**Development of Beta Batteries for Utility Application**
AP-5576 Interim Report (RP128-7); $32.50
Contractor: General Electric Co.
EPRI Project Manager: R. Weaver

**Downwell Pump Reliability: Geothermal Experience Update**
AP-5600 Final Report (RP2559-1); $32.50
Contractor: Radian Corp.
EPRI Project Manager: J. Berning

**Repowering Options Study**
AP-5611 Final Report (RP2565-11); $32.50
Contractor: Florida Power & Light Co.
EPRI Project Manager: H. Schreiber

**Erosion-Corrosion of Materials in Coal-Water Slurries**
AP-5628 Final Report (RP2048-9); $25
Contractor: Lawrence Berkeley Laboratory
EPRI Project Manager: W. Bakker

## COAL COMBUSTION SYSTEMS

**Strategy for Fossil Plant Life Extension at Niagara Mohawk's Huntley-67**
CS-4780 Final Report (RP2596-3); $500
Contractor: Niagara Mohawk Power Corp.
EPRI Project Manager: D. Broske

**Remaining-Life Estimation of Boiler Pressure Parts, Vol. 2: Miniature Specimen Creep Testing**
CS-5588 Final Report (RP2253-1); $400
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: R. Viswanathan

**Effects of Selected Water Treatments and Cathodic Protection on Corrosion and Embrittlement of Condenser Tubes**
CS-5589 Final Report (RP1689-3); $300
Contractor: Ocean City Research Corp.
EPRI Project Manager: B. Syrett

**Engineering Assessment of Condenser Deaeration Retrofits for Cycling Fossil Plants**
CS-5601 Final Report (RP1689-13); $32.50
Contractors: Burns and Roe Enterprises, Inc.; Bechtel National, Inc.
EPRI Project Manager: J. Tsou

**Multitechnique Corrosion Monitoring in Flue Gas Desulfurization Systems: Phase 1**
CS-5605 Interim Report (RP1871-14); $200
Contractor: Corrosion and Protection Centre Industrial Services
EPRI Project Manager: B. Syrett

**Sampling and Analytic Protocol for Advanced $SO_2$ Control By-products**
CS-5625 Final Report (RP2708-1); $47.50
Contractor: ICF Technology Inc.
EPRI Project Manager: D. Golden

**Fossil Unit Performance: 1965–1984**
CS-5627 Final Report (RP1266-31); $32.50
Contractor: The S. M. Stoller Corporation
EPRI Project Manager: T. McCloskey

## ELECTRICAL SYSTEMS

**Optimization of Reactive Volt-Ampere (VAR) Sources in System Planning, Vol. 2: User's Manual**
EL-3729-CCM Computer Code Manual (RP2109-1); Vol. 2, $32.50
Contractor: Scientific Systems, Inc.
EPRI Project Manager: N. Balu

**Advanced Power System Security Analysis Concepts, Vol. 3: New Security Measures and Multiple Contingency Selection Methods**
EL-4522 Final Report (RP1999-1); $40
Contractor: Michigan State University
EPRI Project Manager: M. Lauby

**TLWorkstation Code: Version 1.1; Vol. 8: DYNAMP Manual**
EL-4540-CCM Computer Code Manual (RP2546-1); $25
Contractor: Georgia Institute of Technology
EPRI Project Manager: R. Kennon

**Reliability Evaluation for Large-Scale Bulk Transmission Systems, Vols. 1 and 2**
EL-5291 Final Report (RP1530-2); Vol. 1, $55; Vol. 2, $32.50
Contractor: Power Technologies, Inc.
EPRI Project Manager: N. Balu

**Mathematical Decomposition Techniques for Power System Expansion Planning, Vols. 1–5**
EL-5299 Final Report (RP2473-6); Vol. 1, $32.50; Vol. 2, $32.50; Vol. 3, $25; Vol. 4, $25; Vol. 5, $25
Contractor: Stanford University
EPRI Project Managers: M. Pereira, N. Balu

**Gas-Insulated Substations: Reliability Research Program, Vols. 1 and 2**
EL-5551 Final Report (RP1360-7); Vol. 1, $10,000; EL-5551-CCM Computer Code Manual, Vol. 2, $10,000
Contractor: Ontario Hydro Research
EPRI Project Manager: V. Tahiliani

**Distributed Fiber-Optics Hot Spot Sensor**
EL-5568 Final Report (RP2308-6); $25
Contractor: Battelle, Columbus Division
EPRI Project Manager: J. Stein

**Proceedings: 1987 EPRI PCB Seminar**
EA/EL-5612 Proceedings (RP2028); $55
EPRI Project Managers: V. Niemeyer, G. Addis

**Development of Expert Systems as On-Line Power System Operational Aids**
EL-5635 Final Report (RP1999-9); $25
Contractor: University of Washington
EPRI Project Manager: M. Lauby

**Knowledge-Based Systems for Electric Utility Operation Using the PROLOG Language**
EL-5666 Final Report (RP2473-8); $32.50
Contractor: Union Electric Co.
EPRI Project Manager: M. Lauby

## ENERGY MANAGEMENT AND UTILIZATION

**Demand-Side Management, Vols. 4 and 5**
EA/EM-3597 Final Report (RP2381-4); Vol. 4, $1000 Vol. 5, forthcoming
Contractors: Battelle-Columbus Division; Synergic Resources Corp., Enviro-Management and Research, Inc.
EPRI Project Managers: W. Smith, C Gellings, O. Zimmerman, A. Faruqui

**FORECAST MASTER, User's Manual, Version 2.1**
EM-5309-CCM Computer Code Manual (RP2279-2); $32.50
Contractors: Business Forecast Systems; Quantitative Economic Research, Inc.
EPRI Project Manager: R. Squitieri

**Water-Loop Heat Pump Systems: Assessment Study**
EM-5437 Final Report (RP2480-2); $150
Contractor: Joseph A. Pietsch, P.E.
EPRI Project Manager: M. Blatt

**Sealed Lead-Acid Electric Vehicle Battery**
EM-5471 Final Report (RP2216-1); $25
Contractor: Jet Propulsion Laboratory
EPRI Project Manager: B. Spindler

**Energy Use and Conservation in the Commercial Sector, Vols. 1 and 2**
EM-5578 Final Report (RP2152-1); Vol. 1, $32.50; Vol. 2, $32.50
Contractors: Applied Econometrics, Inc.; Temple, Barker & Sloane, Inc.
EPRI Project Managers: P. Hanser, J. Wharton

**Implicit Discount Rates in Residential Customer Choices, Vols. 1 and 2**
EM-5587 Final Report (RP2547-1); Vol. 1, $32.50; Vol. 2, $25
Contractor: Cambridge Systematics, Inc.
EPRI Project Manager: S. Braithwait

**EMPS-2.1 Computer Program for Residential Building Energy Analysis—Engineering Manual**
EM-5610 Final Report (RP2034-16); $32.50
Contractor: Arthur D. Little, Inc.
EPRI Project Managers: G. Purcell, J. Kesselring

**DSM: Market Research Issues and Methods**
EM-5632 Final Report (RP2548-1); $1000
Contractors: Xenergy, Inc.; Opinion Research Corp.; Battelle, Columbus Division
EPRI Project Managers: W. Smith, L. Lewis

**DSM Commercial Customer Acceptance, Vols. 1 and 2**
EM-5633 Final Report (RP2548-1); Vol. 1, $1000; Vol. 2, forthcoming
Contractors: Xenergy, Inc.; Battelle, Columbus Division
EPRI Project Managers: W. Smith, L. Lewis

## ENVIRONMENT

**Demand-Side Management, Vols. 4 and 5**
EA/EM-3597 Final Report (RP2381-4); Vol. 4, $1000 Vol. 5, forthcoming
Contractors: Battelle-Columbus Division; Synergic Resources Corp., Enviro-Management and Research, Inc.
EPRI Project Managers: W. Smith, C. Gellings, O. Zimmerman, A. Faruqui

**Groundwater Assessment Modeling Under the Resource Conservation and Recovery Act**
EA-5342 Final Report (RP2070-1); $40
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Managers: P. Ricci, R. Wyzga

**Urban Power Plant Plume Studies**
EA-5468 Final Report (RP2736-1); $40
Contractor: TRC Environmental Consultants, Inc.
EPRI Project Managers: G. Hilst, G. Beals

**Proceedings: EPRI Air Quality Modeling Contractors Meeting**
EA-5571 Proceedings (RP1630-21); $32.50
Contractor: SRI International
EPRI Project Managers: G. Hilst, P. Mueller

**Chemical Spill Exposure Assessment Methodology**
EA-5572 Final Report (RP2634-1); $40
Contractor: CH2M Hill
EPRI Project Manager: A. Silvers

**Proceedings: 1987 EPRI PCB Seminar**
EA/EL-5612 Proceedings (RP2028); $55
EPRI Project Managers: V. Niemeyer, G. Addis

**Review of Selenium Thermodynamic Data**
EA-5655 Final Report (RP2020-3); $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: D. Porcella

## NUCLEAR POWER

**Experimental Study of Diversion Cross-Flow Caused by Subchannel Blockages, Vol. 2: Two-Phase Flow**
NP-3459 Final Report (RP1378-1); Vol. 2, $62.50
Contractor: Ecole Polytechnique de Montréal
EPRI Project Manager: M. Merilo

**Application Guidelines for Check Valves in Nuclear Power Plants**
NP-5479 Final Report (RP2233-20); $47.50
Contractor: MPR Associates, Inc.
EPRI Project Manager: B. Brooks

**Decommissioning U.S. Reactors: Current Status and Developing Issues**
NP-5494 Final Report (RP2759-1); $32.50
Contractor: Pentek Inc.
EPRI Project Manager: C. Welty

**Radwaste Generation Survey Update, Vols. 1 and 2**
NP-5526 Final Report (RP1557-26); Vol. 1, $5000; Vol. 2, $5000
Contractor: Analytical Resources, Inc.
EPRI Project Manager: P. Robinson

**Evaluation of High-Energy Pipe Rupture Experiments**
NP-5531 Final Report (RP2176-2); $32.50
Contractors: Structural Integrity Associates, Inc.; S. Levy, Inc.
EPRI Project Manager: A. Singh

**Remote Calibration of Resistance Temperature Devices (RTDs)**
NP-5537 Final Report (RP2254-1); $40
Contractor: Oak Ridge National Laboratory
EPRI Project Manager: J. Weiss

**Tubesheet Expansion Improvements**
NP-5547 Final Report (RPS303-29); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: A. McIlree

**NDE and Mechanical Removal of Sludge in PWR Steam Generators, Vols. 1 and 2**
NP-5563 Final Report (RPS403-2, -4, RP2755-2–11); Vol. 1, $32.50; Vol. 2, $55
Contractors: Anco Engineers, Inc; Babcock & Wilcox Co.; Combustion Engineering, Inc.; Dominion Engineering, Inc.; Foster-Miller, Inc.; LN Technologies Corp.; Westinghouse Electric Corp.
EPRI Project Manager: L. Williams

# CALENDAR

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

**AUGUST**

**9–10**
**Harmonic Effect on Large Induction Motors**
Albany, New York
Contact: Jan Stein (415) 855-2390

**11–12**
**Workshop: Appendix K Relief, Using Best-Estimate Codes**
Cambridge, Massachusetts
Contact: Pal Kalra (415) 855-2414

**30–September 1**
**2d Conference on Cycle Chemistry in Fossil Fuel Plants**
Seattle, Washington
Contact: Barry Dooley (415) 855-2458

**SEPTEMBER**

**15–16**
**5th Annual Workshop Sponsored by NSAC and Operational Reactor Safety Engineering and Review Groups**
San Diego, California
Contact: Bill Reuland (415) 855-2977

**19–21**
**3d National Conference: Environmental and Public Health Effects of Soils Contaminated With Petroleum Products**
Amherst, Massachusetts
Contact: Mary McLearn (415) 855-2487 or Gordon Newell (415) 855-2573

**21–23**
**2d International Symposium: Probabilistic Methods Applied to Electric Utilities**
Oakland, California
Contact: Dick Kennon (415) 855-2311

**OCTOBER**

**4–6**
**FASTCHEM and FOWL: Codes for Modeling the Release, Transport, and Fate of Inorganic Chemicals in Groundwater**
Washington, D.C.
Contact: Dave McIntosh (415) 855-7918

**13–15**
**Fuel Supply Seminar**
Kansas City, Missouri
Contact: Jeremy Platt (415) 855-2628

## Authors and Articles


Hidy


Mankoff


Spencer


Worledge


Yeager


Sursock


Hingorani


Edmonds


Nilsson


White

**The Politics of Climate** (page 4) was written by Michael Shepard, senior feature writer, who consulted with three EPRI vice presidents and their technical staff members.

**George Hidy,** director of the Environment Division since May 1987, was formerly president of the Desert Research Institute of the University of Nevada. Earlier, he directed environmental laboratories for Energy Research and Technology (nine years), Rockwell International (six years), and the National Center for Atmospheric Research (six years).

**Dwain Spencer,** director of the Advanced Power Systems Division since 1979, came to EPRI in 1974 from the Caltech Jet Propulsion Laboratory, where he had worked for 16 years, the final 2 years on loan to the National Science Foundation, designing a program of solar energy research.

**Kurt Yeager,** director of the Coal Combustion Systems Division since 1979, joined EPRI in 1974 after two years with the EPA Office of Research, where he was director of energy R&D planning. He had previously been associate head of environmental systems research at The MITRE Corp. ■

**Building the Smarter Substation** (page 16) was written by science writer John Douglas, assisted by three Electrical Systems Division staff members.

**Narain Hingorani,** director of the division and an EPRI vice president, came to the position 2 years ago, having been director of the Transmission Department since 1983 and an Institute staff member since 1974. He was formerly with the Bonneville Power Administration for 6 years, and before that he spent 11 years in research, teaching, and consulting on the faculties of three British universities.

**Stig Nilsson,** long-time manager of the Transmission Substations Program, has been with EPRI since 1975. He was briefly with Boeing Computer Services in the early 1970s, and before that he was with Sweden's ASEA for 11 years, coming to the United States in 1967 to install and test control equipment on the Pacific Northwest-Southwest HVDC Intertie.

**Lawrence Mankoff** is a project manager specializing in protective relaying and controls. He joined EPRI in April 1987, after 38 years with General Electric, the last 18 years as manager of engineering for power systems. ■

**Simulators: Tough Training for Top Operators** (page 22) was written by Jon Cohen, science writer, aided by two program managers of EPRI's Nuclear Power Division.

**David Worledge** works in safety technology, particularly in accident risk assessment. He has been with EPRI since 1981. Worledge was previously with the United Kingdom Atomic Energy Authority for several years, first in fast reactor studies and eventually as head of the UKAEA systems reliability service. He also worked for two years in fast reactor studies at Sandia Laboratories in Los Alamos, New Mexico.

**Jean-Pierre Sursock** has managed a program of reactor safety control and testing since August 1984. He came to EPRI as a project manager in 1976 after three years in nuclear power engineering with General Electric. ■

**Early Warning for Hydro Generator Failure** (page 30) was written by John Douglas, science writer, with guidance from two staff members of EPRI's Electrical Systems Division.

**James Edmonds,** a project manager in the Plant Electrical Systems and Equipment Program since 1978, focuses on problems of physical stress in generator components. He was formerly with American Electric Power Service for eight years, becoming staff electrical engineer for all rotating machinery on the AEP system.

**J C. White** manages the Plant Electrical Systems and Equipment Program. He has been with EPRI since 1979, following 32 years in electrical machinery engineering with General Electric at Schenectady, New York, where he became manager of product engineering. ■

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